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Transportation Research at the University of California

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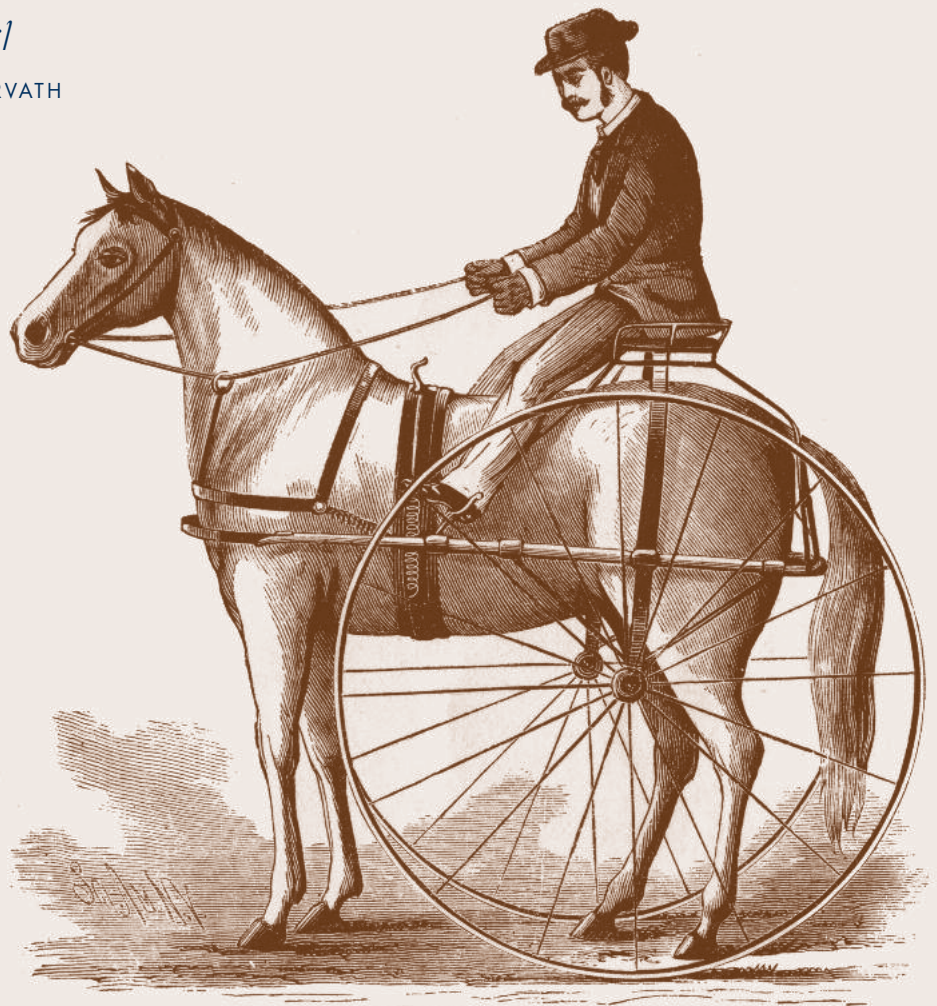
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*The vital last step in research is making the results useful to public decision makers.*

**A**CADEMIC RESEARCH IN TRANSPORTATION may require years of work before the author eventually publishes the results in a professional journal. Developing a theory, collecting relevant data, and conducting rigorous statistical tests are usually necessary before an article is accepted for publication. Then what happens? If the author is lucky, fellow academics and their students will read the article and discuss it. The transportation planners and elected officials who might be able use the results to improve our transportation system, however, will probably never see the article or even hear about the research.

The goal of ACCESS is to make transportation research conducted at the University of California useful for policymakers and practitioners. After the research has been published in an academic journal, the author can prepare a shorter and more readable version for ACCESS, which has the luxury of stressing readability because the journal has already stressed rigor. Anyone who wants greater depth or more detail can refer to the original article. ACCESS can thus present scientific research in plain, intelligent, and even lively prose. Paring down a journal article for publication in ACCESS can catapult academic research into the public policy debate, and help convert knowledge into action.

This year we are grateful for permission to print shorter versions of articles that were originally published in *Environment and Planning*, *Journal of Public Economics*, *Journal of Public Transportation*, *Journal of the Transportation Research Board*, *Journal of Urban Economics*, *Journal of Urban Planning and Development*, and *Transportation*.

Because ACCESS articles are highly readable and well illustrated, we often receive requests to reprint

them, which we grant without charge. This year we have given free reprint permissions to publications ranging from *Arkansas Trucking* (circulation 17,000) to course readers for university classes with only a few students. In many cases, the ACCESS version of an academic article is put on reading lists for university courses more frequently than the original article—probably because of the brevity and readability. Publishing in ACCESS can thus expose scholarly research to transportation students who may eventually put the ideas into practice.

When translating academic research into readable prose, we try to follow the advice of famed *New Yorker* editor William Shawn: “We value coherence. We believe in the printed word. And we believe in clarity. And we believe in immaculate syntax. And in the beauty of the English language.” But easy reading is hard writing, both for authors and editors. In the editing we rely greatly on the contributions of graduate students who spend many hours helping our authors say what they mean. This year we are grateful to Alex Beata, Matthew Bruno, Daniel Caroselli, Michael Clark, Jeremy Cogan, Stephanie Erickson, Niall Huffman, Alexis Lantz, Andrew Lee, Gregory Pierce, Jeffrey Rabin, Ariel Strauss, Jacob Veverka, and Jonathan Yorde. It has been a pleasure to work with them.

Finally, and most importantly, we would like to thank the California Department of Transportation and the United States Department of Transportation for providing the funds necessary to publish ACCESS. Their support enables our authors to take the vital last step in transportation research: making the results useful to public decision makers.

*Donald Shoup*

# What Density Doesn't Tell Us About Sprawl

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BY ERIC EIDLIN

**S**PRAWL HAS NO SINGLE DEFINITION. Many people, however, tend to think of “sprawling” cities as places where people make most of their trips by car, and non-sprawling cities as places where people are more likely to walk, cycle, or take transit. This is why Los Angeles, which has more vehicles per square mile than any other urbanized area, and where transit accounts for only two percent of the region’s overall trips, is considered sprawling, while the New York urbanized area is not. We also know (or think we know) that places where people frequently walk, cycle, or take transit tend to have high population densities, and for this reason we tend to view low density as a proxy for sprawl. But as it turns out, the Los Angeles urbanized area—which in both myth and fact is very car-oriented—is also very dense. In fact, Los Angeles has been the densest urbanized area in the United States since the 1980s, denser even than New York and San Francisco. >

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These facts present a bit of a mystery. If one were to measure sprawl by measuring a region's average level of Vehicle Miles Traveled (VMT), Los Angeles would certainly qualify as sprawling. But if we measure sprawl by population density, LA would not sprawl at all. In fact, it would be the *least* sprawling urbanized area in the country. How can Los Angeles be so dense and yet also exhibit so many characteristics associated with sprawl, including high levels of car travel (both in per capita and absolute terms) and low rates of walking, bicycling and transit ridership?

Part of the answer lies in the vagaries of Census geography. Sprawl is a regional attribute, so when observers point out that LA is denser than New York, they are not talking about the *cities* of Los Angeles and New York. Rather they are talking about the *urbanized area*, which is essentially the combined area of the cities and their suburbs. The other part of the answer is that density by itself—the simple ratio of population to square mile—is not a very useful way to measure sprawl. What matters is the *distribution* of density, or how evenly or unevenly an area's population is spread out across its geographic area. If we look at the density distribution in Los Angeles, we notice that its suburbs are much denser than those of other large U.S. cities, such as New York, San Francisco or Chicago. These high-density suburbs compensate for the comparatively low density of LA's urban core, and, in so doing, increase the average density of the area as a whole. In other words, Los Angeles has both a relatively high density and a relatively *even distribution* of density throughout its urbanized area.

The LA region's combination of high, evenly distributed density puts it in an unfortunate position: it suffers from many of the problems that accompany high population density, including extreme traffic congestion and poor air quality; but lacks many of the benefits that typically accompany more traditional versions of dense urban areas, including fast and effective public transit and a core with vibrant street life. Los Angeles has, to borrow a term coined by urbanist William Fulton, “dense sprawl.” (Or, to be less charitable, it has “dysfunctional density.”) It is too dense to function like classic suburbia, but also has few areas dense enough to be a “city” in the manner of central city New York or San Francisco.

Why does this matter? The point is not to pick on Los Angeles, which has many wonderful attributes to go along with its problems. Rather Los Angeles highlights a weakness in the way we traditionally think about density and sprawl. Planners are often quick to recommend increased density to combat congestion and make cities more livable, but LA shows us that simply chasing density, without thought as to *where* that density is, will not do much to help and might actually make things worse. In the remainder of this article I will examine LA's population distribution in more detail and then discuss how traditional measures of density can mislead planners and transportation policymakers. Finally, I examine three alternative ways to measure density that may be more useful.

#### **DENSITY WITHOUT DOWNTOWN, SPRAWL WITHOUT SUBURBIA**

People are often surprised to learn that Los Angeles is dense. Some of this surprise probably stems from a tendency to associate urban density with busy downtown centers. Many people, when they think about urban density, understandably picture Manhattan or Hong Kong, not LA. And it's true that Los Angeles doesn't have much of a center; it is one of the most decentralized urban areas on earth. But of the five densest metropolitan areas in the U.S., LA is the densest, both in people and jobs. At the same time, however, its *central city* has the *lowest* job density of these five areas, and the second lowest population density (see Table 1). Only six percent of the region's jobs are in the central business district, and only twelve percent are

CITY	METROPOLITAN DENSITY		CENTRAL CITY DENSITY	
	POPULATION per acre (rank)	JOB per acre (rank)	POPULATION per acre (rank)	JOB per acre (rank)
Los Angeles	59 (1)	31 (1)	70 (4)	1,251 (5)
New York	47 (2)	27 (2)	560 (1)	2,444 (1)
Chicago	41 (3)	22 (4)	75 (3)	2,276 (2)
San Francisco	40 (4)	21 (5)	275 (2)	1,839 (3)
Washington DC	34 (5)	24 (3)	68 (5)	1,701 (4)

Source: Newman and Kenworthy (1999)

located in the region's nineteen largest job centers. Downtown Los Angeles is even less significant as a residential area: despite a surge in loft construction over the past decade, its daytime population of approximately 500,000 people is over twelve times larger than its residential population of 40,000. The population of Manhattan, by contrast, only doubles during the day.

So it is clear that Los Angeles lacks a super-dense core like Manhattan. But it also lacks a very low-density suburban periphery. Suburban neighborhoods in the Los Angeles region are much denser than their counterparts in the Northeast and Midwest. Indeed, one might say that they are not *classically* suburban, in the sense that few of them offer large houses on large plots of land, uncongested roads, and easy access to open space.

But while the suburbs of metropolitan Los Angeles are dense compared to the suburbs of other U.S. urban areas, most (with some notable exceptions) are not dense enough to support traditional urban amenities like frequent and high quality public transit and bustling commercial districts with sidewalk cafes and pedestrian-oriented retail. Like the distribution of population in metropolitan Los Angeles as a whole, the distribution of density throughout most of these outlying areas is not clustered at nodes or along densely populated corridors that can be easily served by public transit. It is spread evenly throughout these areas.

#### WHY MEASURES OF AVERAGE DENSITY FALL SHORT

Why do standard measures of density mislead? Two reasons: first, the standard measure relies too much on where the urbanized area's formal boundary is drawn, and second, the measure is determined by total land area, even if some of the land is sparsely populated.

Compare New York and Los Angeles again. By the standard measure, Los Angeles, with 59 people per acre, is considerably denser than New York, with 47. A big part of the reason is LA's dense suburbs, but this explanation is somehow unsatisfying. I suspect that for many people, the fact that Palmdale (a suburb of LA) is denser than White Plains (a suburb of New York) shouldn't lead to the conclusion that Los Angeles is denser than New York. But if we measure density simply by dividing land area into population, that is exactly the conclusion we get.

So is there a better way to measure density? Below I discuss three alternative approaches that might be more helpful in understanding the development patterns of dispersed and polycentric urban regions like LA. One method measures unequal density in the distribution of population; the other two attempt to measure density as it is experienced by the average resident of a given urban area. ➤

**TABLE 1**

Population and Employment Density for Five Densest Metropolitan Areas

*Los Angeles has “dense sprawl.” Or, to be less charitable, it has “dysfunctional density.”*



## MEASURING VARIATION IN THE DISTRIBUTION OF POPULATION

### The Gini Coefficient

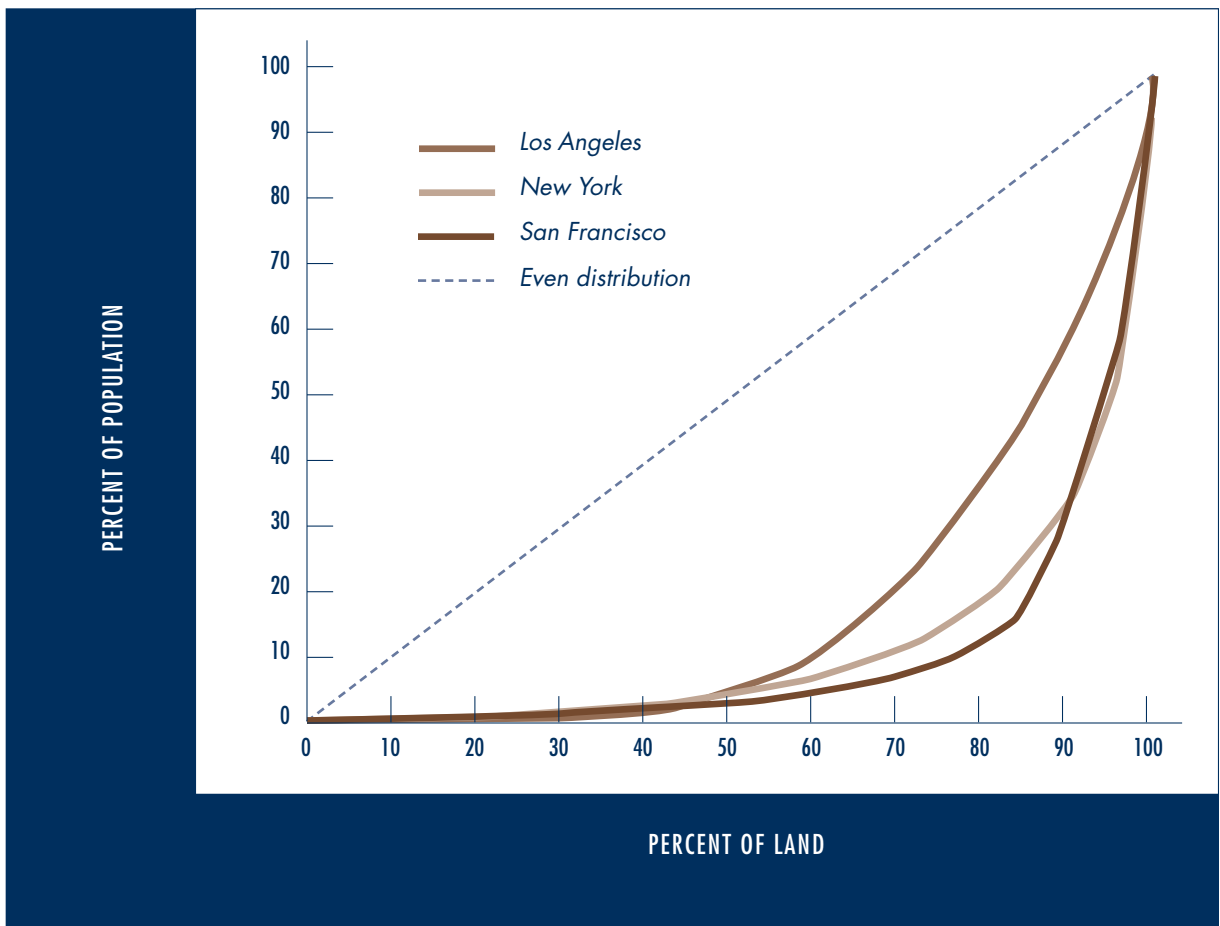
One approach is to measure the extent to which the population density *varies* across an urban area. Using a statistical tool called the Gini coefficient, we can get a sense of the degree of variation for different urban areas. The Gini coefficient is based on the Lorenz curve, a cumulative frequency curve that compares the distribution of a specific variable (in this case, population density) with a uniform distribution that represents perfect equality.

Figure 1 shows the distribution of population for three urbanized areas (Los Angeles, New York, and San Francisco) by Census tract, relative to the proportion of land. The diagonal line represents a perfectly equal distribution, or a Gini coefficient of 0. The more the curve strays from the diagonal line, the greater the variation in population density. Perfect inequality—if all the residents of a city inhabited one single census tract—would be represented by a value of 1.

Measuring inequality in this way, the Gini coefficient is 0.65 for Los Angeles, 0.77 for New York, and 0.80 for San Francisco. In graphical terms, the Los Angeles curve stays closer to the diagonal line—the line representing an even distribution—than the curves for New York or San Francisco. This might help explain why Los Angeles appears to be less dense

**FIGURE 1**

Population Distribution in the Los Angeles, New York and San Francisco Urbanized Areas



(and therefore also less “urban” in the classical sense discussed earlier) than San Francisco and New York, even though its average population density is higher. The population of all three urbanized areas is distributed unevenly. However, this distribution is much more even in Los Angeles than it is in New York and San Francisco.

The difference between Los Angeles and the other two regions becomes even more pronounced when one looks only at the most densely populated census tracts in each urbanized area. In Los Angeles, 40 percent of the population live on the most densely settled 10 percent of land. By way of comparison, roughly 66 percent of New York’s population, and 67 percent of San Francisco’s, live on the most densely settled ten percent of the land. By looking even further to the right of the graph, one finds that 25 percent of the population in Los Angeles lives on the densest 5 percent of the land. By contrast, 46 percent of San Francisco’s population, and more than 50 percent of New York’s, live on the densest 5 percent of the land. The overwhelming majority of New York and San Francisco’s residents live on a very small portion of their urbanized areas’ land. But this is much less the case in LA.

### *Perceived Density*

Another approach to measuring density, which was developed separately by both Gary Barnes and Chris Bradford, is to use “perceived” or “weighted” density. The purpose of perceived density is to capture the density of the place in which the average person lives. A good way of conceptualizing the difference between “standard density” and “perceived density” is that where standard density measures the *average amount of land* around each resident of a city, perceived density measures the *average number of people* around each resident of that city. Measuring perceived density involves four steps:

1. Divide the city into small geographic units such as census tracts.
2. Calculate the standard density of each of these census tracts.
3. Assign a weight to each census tract that is equal to its share of the total population of the city.
4. Average the weighted densities of all of the city’s census tracts.

This produces a weighted or “perceived” density for the city.

For the purpose of illustration, Bradford offers the extreme example of a fictitious city called “Metropolis.” Metropolis has a central core of 100,000 residents who live on ten square miles of land and a suburb with 10,000 residents who live on 100 square miles of land. The standard density of Metropolis is 1,000 people per square mile. However, since 90 percent of the population—those who inhabit the core—live in a very dense environment, this standard density number has little bearing on the way most residents experience their city. By giving the core’s density a weight of 90 percent and the suburb’s density a weight of 10 percent—weights that are equal to the respective proportions of the city’s residents that inhabit each part—we get an adjusted density of 9,100 people per square mile, a number that more closely approximates the density at which the average resident of Metropolis lives.

### **PERCEIVED DENSITY RANKING OF U.S. URBANIZED AREAS**

Using data from the 2000 U.S. Census, Bradford calculated the perceived densities of the largest urbanized areas in the U.S. He began with data for each census tract that is partially or wholly contained within each of the urbanized areas. He then calculated each census ➤





tract's share of the urbanized area's total population. From there he assigned each census tract a weight equal to its share of the population and averaged the weights to get the perceived density for the urbanized area. Table 2 below shows the perceived densities of the 15 largest urbanized areas in the US..

The resulting measures of perceived density probably align more closely with common perceptions of urban density. New York ranks head and shoulders above other urbanized areas, with a perceived density of over 33,000 people per square mile. San Francisco comes in second, with a perceived density of over 15,000 people per square mile, while Los Angeles drops from first place to third, with a perceived density of about 12,500 people per square mile. This ranking may still strike many as surprisingly high, given that Los Angeles remains ahead of cities that most people would intuitively think of as being dense, including Chicago, Philadelphia, Boston, and Washington, D.C.

#### DENSITY GRADIENT INDEX

Bradford pushed the concept of perceived density a step further by developing the density gradient index. The density gradient index, which is the ratio of perceived density to standard density, is an indication of the unevenness of population distribution—or, to use Bradford's terminology—a measure of “clumpiness.” Table 2 also shows the density gradient index for each urbanized area.

**TABLE 2**

Perceived Densities, Density Gradient Index, and Non-Automobile Commuting: 15 Largest Urbanized Areas

URBANIZED AREA	PERCEIVED DENSITY (people per square mile) (rank)	DENSITY GRADIENT INDEX (rank)	PERCENTAGE OF COMMUTES BY PUBLIC TRANSIT (rank)	PERCENTAGE OF COMMUTES BY PUBLIC TRANSIT OR WALKING (rank)
New York--Newark, NY--NJ--CT	33,029 (1)	6.2 (1)	30.6% (1)	36.5% (1)
San Francisco--Oakland, CA	15,032 (2)	2.2 (5)	15.9% (2)	20.5% (2)
Los Angeles--Long Beach--Santa Ana, CA	12,557 (3)	1.8 (8)	5.8% (8)	8.2% (8)
Chicago, IL--IN	10,270 (4)	2.6 (4)	11.9% (4)	14.7% (5)
Philadelphia, PA--NJ--DE--MD	8,457 (5)	3.0 (3)	9.7% (6)	13.3% (6)
Boston, MA--NH--RI	7,711 (6)	3.3 (2)	11.6% (5)	16.1% (4)
San Diego, CA	7,186 (7)	2.1 (6)	3.1% (12)	5.0% (11)
Washington, DC--VA--MD	6,835 (8)	2.0 (7)	15.7% (3)	18.6% (3)
Miami, FL	6,810 (9)	1.6 (12)	3.6% (10)	5.3% (9)
Phoenix--Mesa, AZ	5,238 (10)	1.4 (14)	2.5% (13)	4.1% (13)
Detroit, MI	4,955 (11)	1.6 (10)	1.7% (15)	3.0% (15)
Seattle, WA	4,747 (12)	1.7 (9)	7.6% (7)	10.3% (7)
Dallas--Fort Worth--Arlington, TX	4,641 (13)	1.6 (11)	1.9% (14)	3.2% (14)
Houston, TX	4,514 (14)	1.5 (13)	3.2% (11)	4.6% (12)
Atlanta, GA	2,362 (15)	1.3 (15)	4.0% (9)	5.1% (10)

Not surprisingly, New York is also the urbanized area with the highest density gradient at 6.2. Interestingly, the urbanized areas with the next highest density gradients after New York are Boston and Philadelphia—neither of which make even the top ten for standard density, and which only rank sixth and fifth, respectively, in terms of perceived density. The source of Boston and Philadelphia’s high density gradients is almost certainly their age and their resulting urban design; they are older cities with large downtown cores and extensive public transit systems that were developed prior to the automobile era. As a result, development in these urbanized areas naturally clustered around their public transit lines, and the distribution of density within them is therefore very “clumpy” in comparison to cities like Los Angeles, Phoenix and Miami that experienced their greatest period of growth after auto ownership had already become widespread.

Bradford did a regression analysis to analyze the relationship between perceived density and commute mode (the final two columns of Table 2). He found virtually no association between standard density and the percentage of workers commuting by public transit or walking, but a strong association between perceived density and commuting by transit or foot, and an even stronger association between the density gradient index and the percentage of workers commuting by transit or by foot.

## CONCLUSION

Many urbanists admire places like Boston, New York and San Francisco, which give their residents a wide range of transportation options and have charming multimodal streets. Many urbanists admire Los Angeles as well, of course, but recognize that it is often a difficult place to walk, bike or use public transportation. However, planners who seek to emulate Boston or New York, or to avoid the less desirable elements of LA, will go astray if they simply focus on increasing density. The urban form of older metropolitan areas is one of great *variance*, not great density. The New York urbanized area offers its residents both a super-dense, vibrant core and a low-density suburbia. The places where land is used very intensively in the center often see it used much less intensively on the outskirts. While it is possible to have an area that contains nothing but extraordinarily high density, such places are unusual, and often islands (think Hong Kong or Singapore).

Acknowledging these land use patterns should make us question some conventional planning goals. We might say we want more density or less sprawl. We might even say that we simply want more places to look like San Francisco or New York. But what *exactly* are we trying to accomplish by doing this? Do we want super-dense urban centers, or very-low density suburbs, or both? These aren’t easy questions to answer, and standard measures of density will offer us little help in trying to answer them.

It is also important to realize that no measure of density, no matter how comprehensive, can capture every dimension of sprawl. Much of what we consider sprawl is determined less by the density of people or jobs, and more by how buildings and parking are arranged on the street, and whether streets are designed in a way that makes walking and biking safe and comfortable. Nevertheless, in the future planners and policymakers might find it useful to assess the perceived density of the places they are trying to improve. Policymaking is about people, after all, so perhaps we are better off examining density as people experience it. ♦

## FURTHER READING

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# Falling Immigration Rates Mean Falling Transit Ridership

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BY EVELYN BLUMENBERG  
AND ALEXANDRA NORTON

**F**ROM ALMOST EVERY ANGLE, immigration generates interest and controversy. Scholars, pundits and policymakers regularly debate immigration and its effects: on culture, on jobs, on schooling. In particular, both academic and popular commentators have focused on whether immigration is associated with increases in unemployment, use of public benefits, or crime. Examinations of these questions have generally revealed that immigration has no effect, or that the effect, if present, is small. Even in the heated debate about immigration and employment, which receives the most popular attention, academics on both sides agree that the effects, be they negative or positive, are modest when compared to the economy as a whole.

Less attention has been paid to an area where immigrants *do* have a substantial impact: public transportation. Immigrants comprise a large and growing segment of the population, and are twice as likely as native-born workers to commute by public transit. In California, for example, immigrants comprise just over a quarter of the population (27 percent), but more than half of all transit commuters.

Immigration has contributed significantly to transit ridership in California, and has been responsible for almost all ridership growth since the 1980s; without immigration, transit use in the state would have declined. This ridership gravy train, however, is unlikely to last. The longer immigrants stay in the country, the less likely they are to use transit, and the number of new immigrants is projected to fall. One way transit agencies can address the potential loss of immigrant riders is to better meet the needs of those (fewer) immigrants who will be newly-arriving—perhaps by enhancing transit services in the dense urban neighborhoods that continue to serve as immigrant ports of entry. In what follows we discuss the role that immigrants play in transit ridership, why immigrants have that role, and how that role is likely to change. We focus on California, because California has long had more immigrants than any other state and therefore provides a useful illustration of the dynamics we describe. Because reliable data on transit use by nativity are only available for the journey to work, we analyze transit commutes and use this as a proxy—albeit an imperfect one—for overall transit ridership.

## IMMIGRANT TRANSIT USE

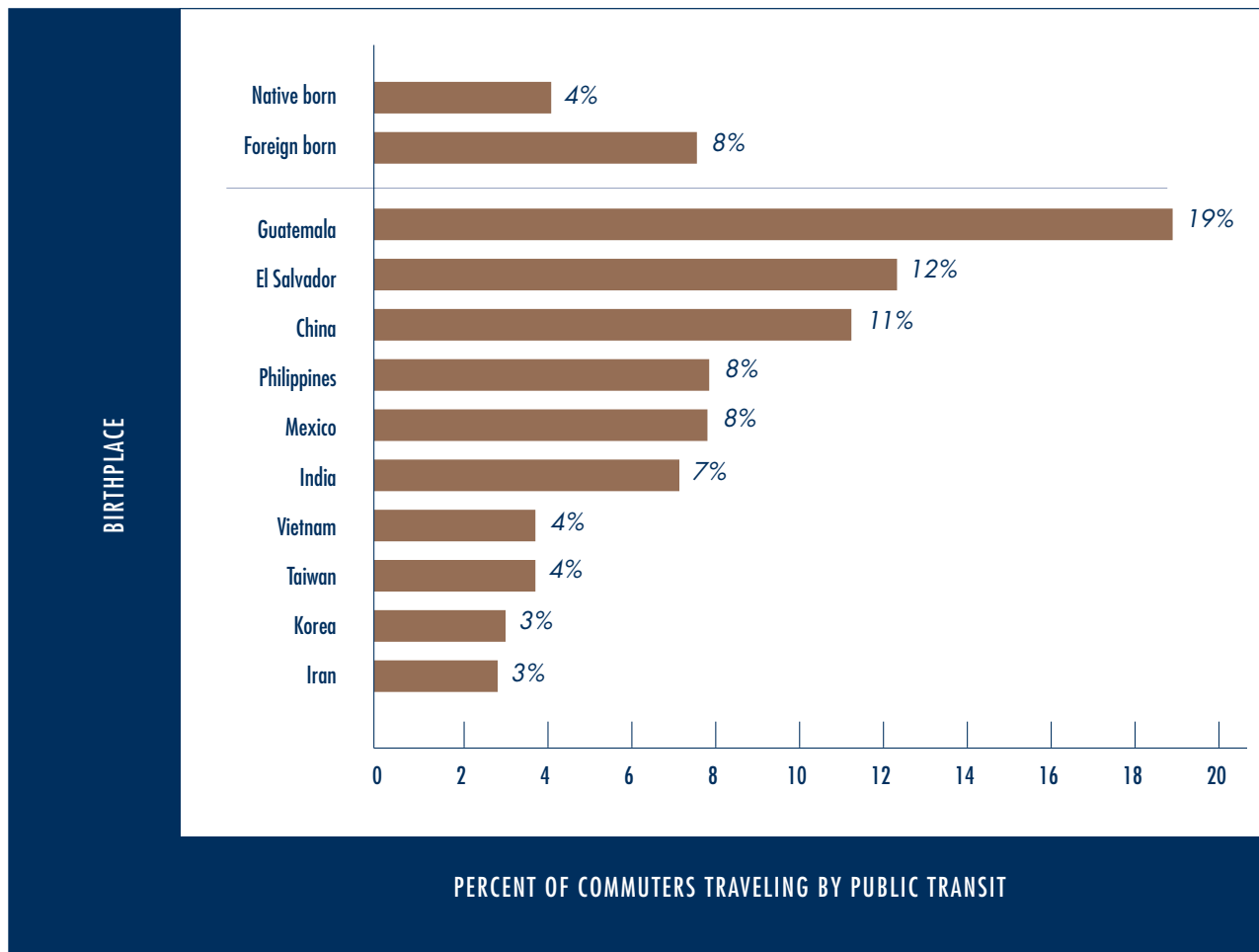
The fact that immigrants use transit much more than the native born does not mean that most immigrants use transit; it means very few native born do. Most immigrants, like most other American commuters, travel to work by automobile. In 2006–08, almost 90 percent of California’s foreign-born population traveled to work by private vehicle, and only 8 percent by public transit. Nevertheless, as Figure 1 shows, immigrants in California commute by public transit at rates twice that of native-born workers. Immigrants are not a monolithic group, however, and there are substantial differences in public transit commuting across immigrant groups and urban areas. The ten immigrant groups listed in Figure 1 represent 78 percent of the foreign-born workers in California, and their transit usage rates vary widely. For example, almost a fifth of Guatemalan immigrants commute by public transit, compared to only three

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**FIGURE 1**

Transit Use by Nativity and Place of Birth, California (2006–2008)



Source: Steven Ruggles, J. Trent Alexander, Katie Genadek, Ronald Goeken, Matthew B. Schroeder, and Matthew Sobek. 2010. Integrated Public Use Microdata Series: Version 5.0 [Machine-readable database]. American Community Survey, 2006–2008. Minneapolis: University of Minnesota.

percent of immigrants from Korea and Iran, who use transit less frequently than native-born workers.

Immigrant transit use can be explained by a number of factors. Immigrants are more likely than native-born workers to have lower incomes, and therefore less likely to be able to afford automobiles. Further, many immigrants—at least initially—settle in large urban areas where high population densities make transit service feasible and convenient. And a number of immigrants settle in ethnic enclaves, residential neighborhoods where local businesses, services, and institutions cater to the needs of co-ethnics (Chinatowns are a classic example). These neighborhoods are often quite dense, and driving in them is inconvenient for anyone, immigrant or non-immigrant. But immigrants might be more likely to make most of their trips in that neighborhood, as a result of ethnic attachment. Where a native-born resident might take advantage of car-friendly alternatives nearby, immigrants might run more of their errands and arrange more of their daily activities within the dense enclave, and as a result be less likely to drive and more likely to take >





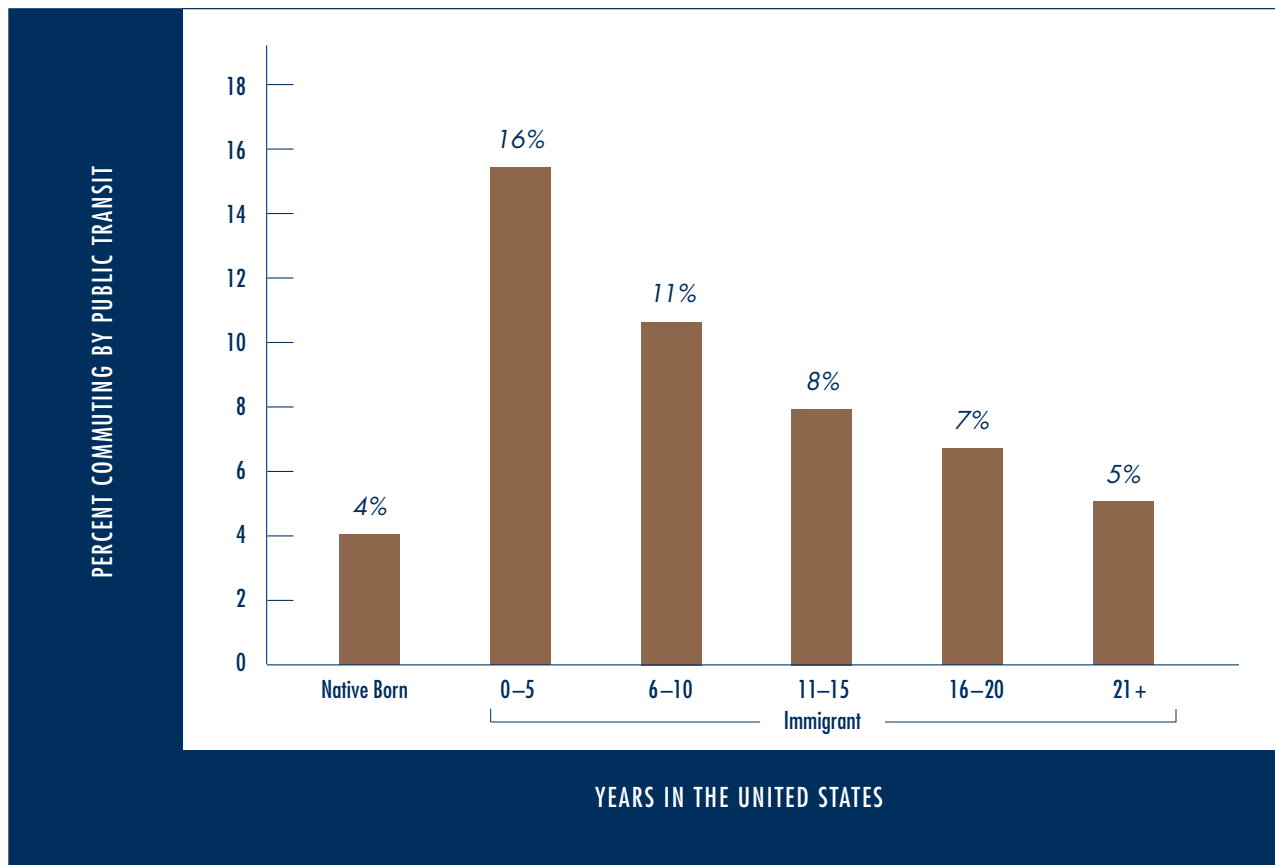
public transportation. Cultural and legal factors also may help explain immigrant transit use. Many immigrants arrive in the U.S. from countries where automobile ownership is extremely low and transit use is high. Immigrants' lack of driving experience and prior familiarity with transit may help to explain their continued use of transit in the U.S. Moreover, some immigrants want to drive but are legally prohibited from doing so. In California and many other states, people must show proof of legal presence in the U.S. to obtain a driver's license. Therefore, undocumented workers—who constitute approximately 9 percent of California's labor force—are not legally eligible to drive.

#### **TRANSPORTATION ASSIMILATION**

Over time, immigrants behave more and more like the native born, and transportation is no exception to this trend. Immigrants who arrive as transit users often graduate to cars. But automobiles are expensive to buy and operate, and ownership is only possible when households have the incomes necessary to manage these costs. Recent immigrants (i.e., those in the U.S. less than six years) have incomes substantially lower than more established immigrants and, as Figure 2 shows, they use transit the most. Sixteen percent of recent immigrants commute by public transit, a rate four times that of native-born commuters, and over three times that of immigrants who have been in the country over 20 years.

**FIGURE 2**

Public Transit Use by Nativity and Years in the U.S., California (2006–2008)



Source: Steven Ruggles, J. Trent Alexander, Katie Genadek, Ronald Goeken, Matthew B. Schroeder, and Matthew Sobek. 2010. Integrated Public Use Microdata Series: Version 5.0 [Machine-readable database]. American Community Survey, 2006–2008. Minneapolis: University of Minnesota.

As immigrants assimilate economically, they gradually assume the auto-oriented travel patterns of the native-born. Transit use among immigrants steadily declines the longer they are in the country, and after more than 20 years in the U.S. immigrants commute by public transit at roughly the same rate as the native-born workers. Among the major racial and ethnic groups, Hispanic immigrants experience the greatest decline in transit use over time; however, their public transit use initially is so high (26 percent) that even after 20 years they remain more likely to use public transit (6 percent) than both other immigrant groups and the native born.

Income alone is not responsible for immigrants' migration away from transit over time. In general, economic assimilation enables, and occurs in conjunction with, spatial assimilation, which further motivates a shift from public transit to driving. Many immigrants initially settle in ethnic enclaves, because the residents of the enclaves can help new arrivals adjust to life in the United States by providing assistance with accommodations, employment, and other services. Historically, these ethnic neighborhoods have emerged in dense central cities where transit is cost-effective and convenient. ➤



Over time, however, many immigrants become more affluent and relocate to the suburbs. In California, 41 percent of recent immigrants live in the central city, compared to only 32 percent of immigrants who have lived in the U.S. more than 20 years. Transit service in the suburbs is often limited and travel distances are frequently long, making cars a more desirable mode of travel.

Finally, regardless of whether they live in a suburb or a central city, a growing percentage of immigrants have moved, both in California and nationally, to regions that are less urban. In 1988, almost half (47 percent) of legal immigrants to California stated that they would settle in Los Angeles (39 percent) or San Francisco (8 percent). By 2008, however, this figure had fallen to 36 percent—with 32 percent planning to live in Los Angeles and 4 percent in San Francisco. Over this same time period, immigrants flooded into outlying low-density counties such as Riverside and San Bernardino—counties that experienced rapid population growth in general. Between 1988 and 2008, Riverside and San Bernardino increased the size of their immigrant populations by a whopping 560 and 315 percent, respectively. Yet transit service in these metropolitan areas is far less extensive than in Los Angeles or San Francisco, and immigrants who move to these outlying regions are more likely to be dependent on cars.

#### IMMIGRANT ASSIMILATION AND TRANSIT COMMUTING

Cumulatively, the trends we discuss above have affected the size and composition of public transit commuters in California. Figure 3 uses Census data from 1980, 1990, 2000, and 2006–08 to show changes in the number and composition of transit commuters. To distinguish the contribution of recent immigrants from more established immigrants, immigrants are categorized as follows: immigrants who at the time of the survey had lived in the U.S. for less than six years, and more settled immigrants who had lived in the U.S. for six years or more. Between 1980 and 2006–08, the number of transit commuters in California grew by over 200,000 people, an increase of almost 40 percent. Yet this increase was driven almost entirely by immigration. Despite dramatic increases in public transit investment over this period, the number of native-born transit commuters remains slightly below 1980 levels.

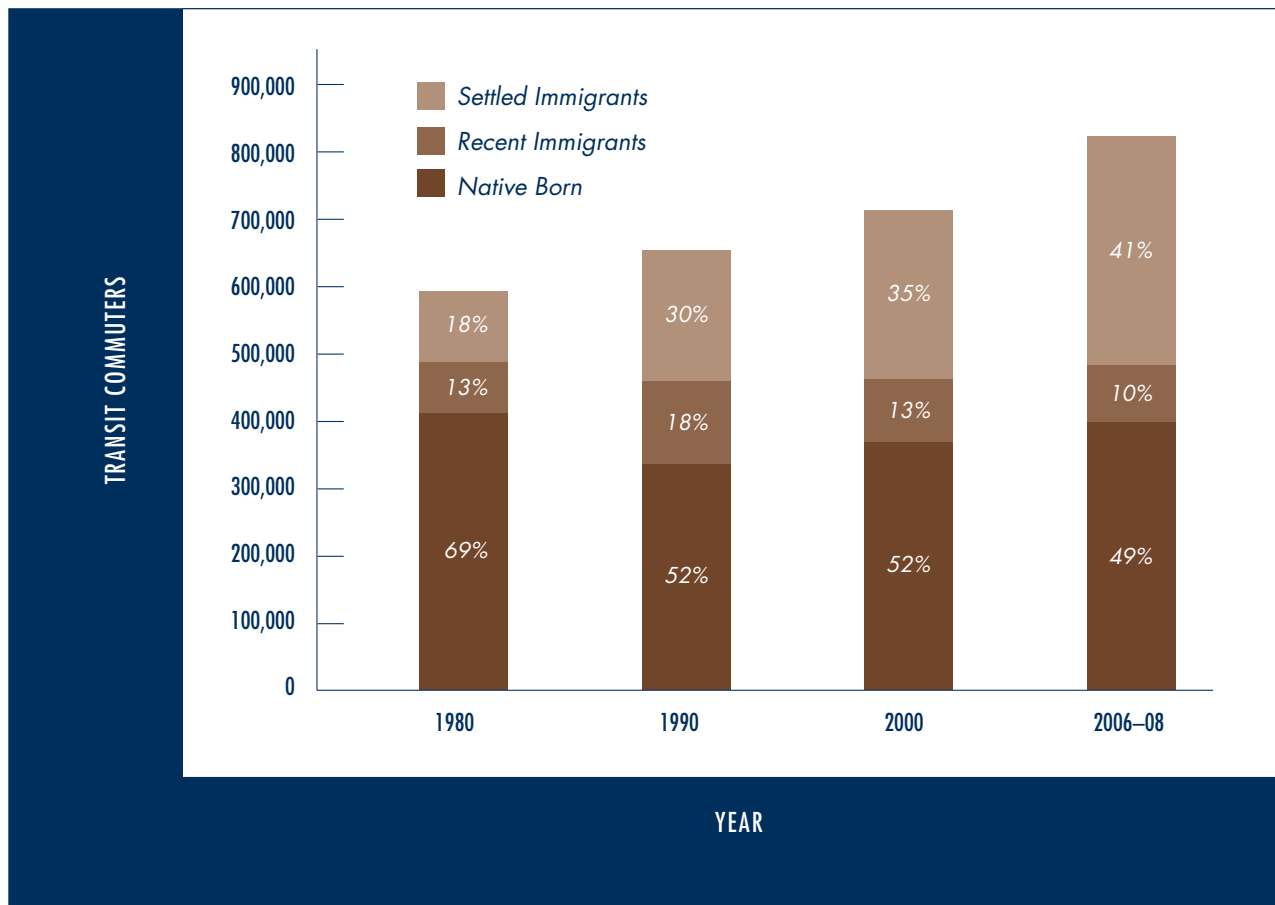
Immigrants, who accounted for 30 percent of all transit commuters in 1980, represented 51 percent of all transit commuters by 2006–08. Among these immigrant transit commuters, the majority are Hispanic (65 percent) and the remainder Asian (25 percent), White (7 percent) and Black (2 percent). In some California metropolitan areas, the percentage of immigrant transit commuters is substantially higher than the state average. Immigrants in the Los Angeles metropolitan area, for example, account for less than half of all workers, but more than two-thirds (67%) of all transit commuters.

Note, however, that immigrants' *propensity* to use transit did not rise. Quite the opposite—the share of immigrants using transit fell from 11 percent in 1980 to 8 percent in 2006–08. So the increased immigrant share of overall transit ridership was due entirely to the substantial growth in the immigrant population. But the number of new immigrants has fallen steadily since 1990. This decline in immigration has large implications for the future of transit ridership in California. The largest growth in immigrant transit commuting—a 70 percent increase—occurred during the 1980s, when immigration to both the U.S. and California rose rapidly. Immigration peaked in 1991, however, when almost 2 million legal immigrants and refugees entered the U.S. In the subsequent decade both



**FIGURE 3**

Transit Commuting, California (1980, 1990, 2000, 2006–08)



Source: Steven Ruggles, J. Trent Alexander, Katie Genadek, Ronald Goeken, Matthew B. Schroeder, and Matthew Sobek. 2010. Integrated Public Use Microdata Series: Version 5.0 [Machine-readable database]. American Community Survey, 2006–2008. Minneapolis: University of Minnesota.

immigration growth and the growth in immigrant transit commuters slowed—the number of immigrant transit commuters increased modestly by 12 percent.

In the absence of immigrants, the number of transit commuters in California would be less than half what it is today. The future of public transit ridership in California therefore rests in large part on how many immigrants we will have, and how these immigrants will choose to travel. Most evidence suggests that in the near future we will have fewer immigrants, and those immigrants will tend to drive. Immigration to the United States is slowing, dampened by increased border enforcement and the recent recession. So too has immigration to California. From 2002 to 2009, legal immigration to the state fell by 21 percent. The decline was more than twice as rapid among immigrants from Mexico and Central America (45 percent), the population groups that are most likely to use public transit. Moreover, unauthorized immigration to California—much of it from Mexico—seems to be at a standstill. Therefore, those immigrants who do arrive, and those already here, will probably continue to assimilate to automobile use, a trend that is likely to accelerate with the growing use of automobiles worldwide. ➤

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## GROWING THE MARKET FOR PUBLIC TRANSIT

Forecasting the future is difficult, particularly since immigration is influenced by federal policy that is subject to change. However, trends in immigration, immigrant transit use, and immigrant residential location suggest that transit agencies in California and other traditional immigrant ports of entry ought to be concerned about their ridership. All signs point to the foreign-born population—a historically dependable transit market—growing at a slower pace and continuing to assimilate to automobiles.

Transit agencies must either find ways to retain immigrant riders or fill the ridership gap with other markets. In the last ten years, transit researchers have recognized the importance not only of attracting new choice riders, but also of retaining existing riders. In fact, retaining existing riders may well be a more cost effective strategy for maintaining transit ridership levels. Given the high percentage of immigrants who have first-hand experience using public transit, immigrants ought to be an important group around which transit agencies target their retention efforts.

Some transit agencies already have adopted strategies to better serve immigrant riders; however, the effects of these programs are unknown. For example, many transit agencies provide information in multiple languages to improve the transit experience of linguistically-isolated riders. While important, language services should be only one component of much larger efforts to improve transit services for immigrants. Focus groups with immigrant transit users show that their needs are similar to those of native-born transit riders; they want service that goes to more places at more times, more frequent service, easier transfers, and they want to feel safe and comfortable both while riding transit vehicles and while waiting for them to arrive. To better capture the immigrant market and potentially slow immigrants' assimilation to cars, transit service enhancements could be targeted to immigrant ports of entry. Another promising approach—one that already has emerged—emphasizes alternatives to traditional fixed-route, fixed-schedule transit service. Such alternatives include a range of both formal and informal services such as taxis, vanpools, minibuses, jitneys, demand-responsive vans, station cars and bicycles, and limited route-deviation bus service—options that already are provided in some communities.

Immigrants are an important and, in some places, the most important segment of the public transit market. Immigrant reliance on transit, however, is a particularly disquieting trend for transit managers in places where immigration is slowing, such as Los Angeles, New York and Chicago. Transit agencies must plan for these changes. To retain their most reliable customers, transit managers must understand the dynamics of immigrant travel behavior and the transit needs of their immigrant ridership. In states such as California, failure to do so—holding all other trends constant—will have grave consequences for the future of public transit. ♦

# ELECTRIC TWO-WHEELERS IN CHINA

## Promise, Progress and Potential

BY CHRISTOPHER CHERRY

**E**LECTRIC TWO-WHEELERS HAVE TRANSFORMED the way people move in most Chinese cities. In just ten years, growth in electric two-wheelers—a category that includes vehicles ranging from electric bicycles to electric motorcycles—has substantially increased the total number of vehicles in China. Electric bike sales began modestly in the 1990s and started to take off in 2004, when 40,000 were sold. Since then, over 100 million have been sold and now more than 20 million are sold each year. Electric two wheelers, in short, represent the first mass-produced and mass-adopted alternative-fuel vehicles in the history of motorization. ➤



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For anyone interested in alternative fuel vehicles, the dramatic success of electric two-wheelers in China merits attention. How did this explosive growth occur? What have the results been? And what is the potential for electric two wheelers to spread elsewhere around the globe? In this article I examine these questions. Electric two-wheelers have filled an important and otherwise underserved niche in the China's crowded transportation system. Electric two-wheelers can maneuver through congested streets. They can be charged from traditional wall outlets and often have a removable battery, allowing them to be charged indoors. And they have some of the lowest emissions of any type of motorized transportation. For residents of dense Chinese cities, electric two-wheelers provide a high level of door-to-door mobility at low cost.

But two-wheelers are not without their critics. Regulations on the production and operation of two-wheelers have been in place since 1999, but these rules are only loosely followed. Two-wheelers are getting larger and faster, and as they get bigger, confusion about how to classify them increases. Are they motorcycles? Are they bikes? The increased speed and power of the two-wheelers also raises concerns about safety, and threatens to diminish some of their environmental benefits. The question of how clean two-wheelers are is also a complicated one, because while their tailpipe emissions are low, they nevertheless create emissions in the places where their electricity is generated.

Nor is it entirely clear whether two-wheelers will spread abroad. The popularity of electric two-wheelers in China owes in part to severe restrictions on some competing modes. Whether electric two wheelers would be as popular in the absence of such regulations is an open question.

## THE RISE OF ELECTRIC TWO-WHEELERS

China's electric two-wheeler growth has been spurred by two notable policies from the central government. First, in 1999, the government designated certain electric two-wheelers as bicycles. To be considered a bicycle, an electric two-wheeler was required to have a bicycle-style design with functioning pedals, weigh less than 40kg, and have a maximum speed of 20km/h. This classification meant, among other things, that qualifying electric two-wheelers could travel in the bicycle right-of-way, that they did not require licensing and registration, and that users did not need a driver's license. These advantages made motorized travel available to many people who would otherwise be unable to use it.

Second, many cities severely restricted the ownership and use of gasoline motorcycles in their urban cores. In a nation with crowded roads and restrictions on gasoline motorcycles, it is perhaps not surprising that a low-cost vehicle that ran on electricity and could travel in bicycle rights-of-way became popular.

Early electric two-wheelers were electric bicycles, generally equipped with a small hub motor and battery pack attached to the frame. These bikes operated on some combination of human-power and electric-power. As technology evolved and demand for larger vehicles grew, producers of electric two-wheelers began to ignore the limits on vehicle speed and weight. Regulation was lax, and consumers wanted faster and heavier two-wheelers that mimicked gasoline scooters. Soon these faster and heavier two-wheelers were common.

Higher speeds have undeniable benefits to users, but higher speeds can also have costs in the form of safety—both the safety of users and the safety of the public. Electric scooters have many of the features of traditional gasoline scooters, often including speedometers, turn signals, brake lights, disk brakes, and headlights. These features can potentially make scooters safer than bikes, but the scooters' increased speed and weight, which increase the severity of any crash, may counteract any safety benefits from their greater visibility and stopping power. As a result, bicyclists became increasingly concerned about sharing their lanes with larger, more powerful scooters.

In response to the perception that two-wheelers had become unsafe, several cities imposed more stringent regulations, forbidding electric scooters in urban centers while gradually allowing higher speeds and weights in outlying areas. And in December 2009, the central government reiterated its commitment to the "20/40 rule" mandating that two wheelers maintain a 20km/hr speed limit and 40kg weight in order to be classified as electric bicycles. Faster and heavier vehicles can still be manufactured, but they are now classified as electric motorcycles, requiring registration and driver licensing. The classification also moves electric scooters out of the bicycle lane. However, the central government continued to allow local governments some latitude in enforcing this new regulation. Therefore, the true impact of this pronouncement may be limited.

## TWO-WHEELERS AND MODE SHIFT

Has the growth in two-wheelers resulted in a significant shift in travel modes? Although China's electric two-wheelers are most similar to bicycles and motorcycles, they compete for ridership not just with other two-wheeled vehicles, but also with buses. A series of surveys in several major cities over four years shows the effect of electric two-wheelers on other transportation modes (Figure 1). In Kunming and Shanghai, which both have high quality transit systems, a majority of the people using electric >



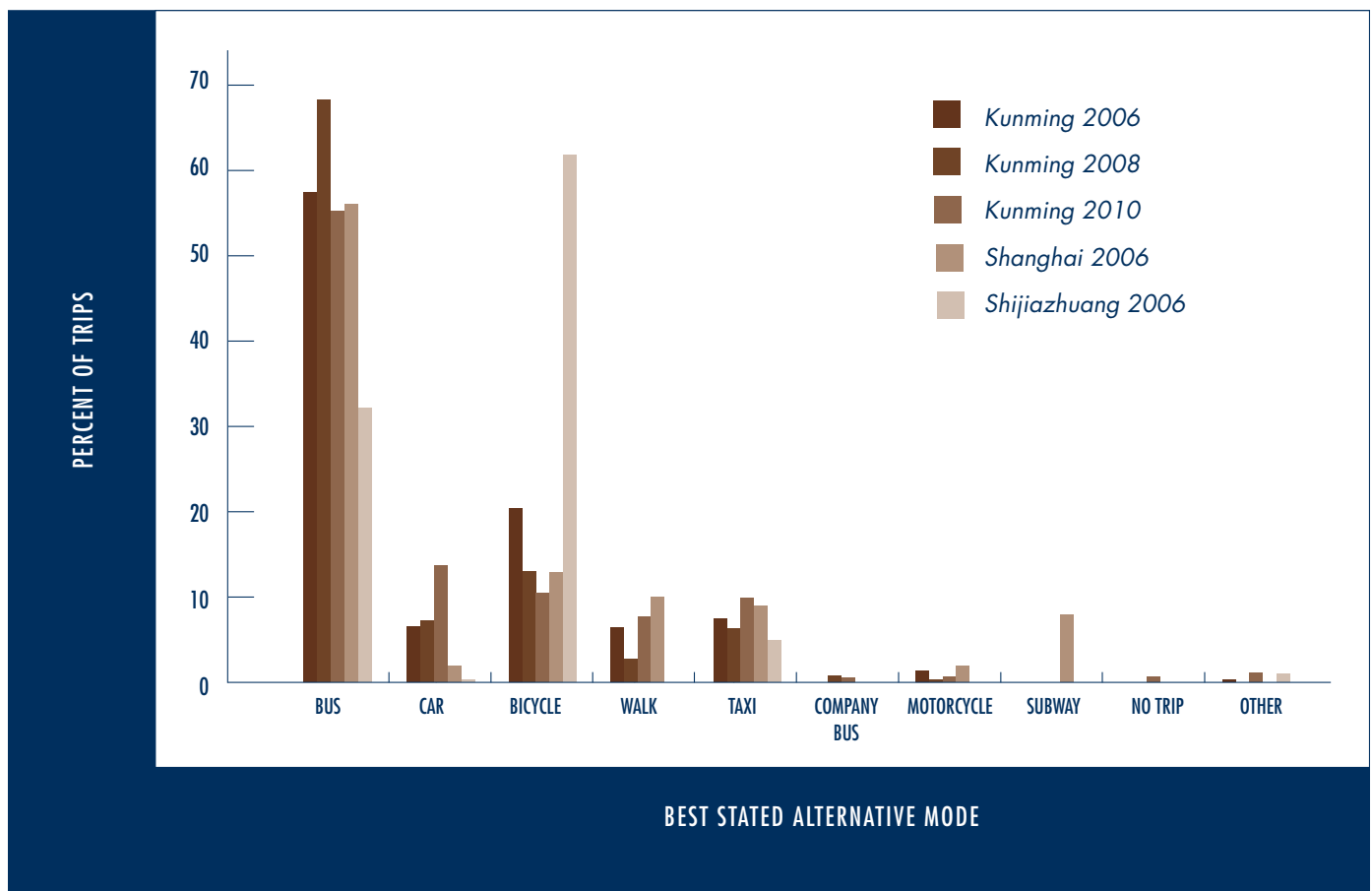
two-wheeler would otherwise be bus riders. In Kunming, over a four year period, electric bike riders seem to be capturing more of the bus mode share and the overall trend toward motorization is also pushing bicycle ridership down. In Shijiazhuang, users of electric two-wheeler riders would more likely be bicyclists than bus-riders. The share of two-wheeler riders who would otherwise use cars in some form (be it a personal vehicle or taxi) is relatively small but environmentally significant (cars have much higher emissions than electric two-wheelers, as I discuss below, so taking even a small number of them off the road can substantially reduce pollution). In Kunming, the share of electric two-wheeler users who would otherwise use cars has increased from 1 in 6 in 2006 to 1 in 4 in 2010.

**ENVIRONMENTAL IMPACTS**

Part of the consumer appeal of electric two-wheelers is their low cost, and their cost is low in part because they are low-weight and low-power, making them among the most efficient vehicles on the road. The electricity costs of a two-wheeler are about 0.2¢ per kilometer. Battery replacement costs can be higher, about 1¢ per km, depending on battery size and fluctuations in lead prices. By way of comparison, gasoline costs for cars average 8¢ per kilometer and for motorcycles 3¢ per kilometer. The average bus trip also costs 3¢ per kilometer.

**FIGURE 1**

Survey Response: Which mode would you choose if electric two-wheeler became unavailable (by trip)?

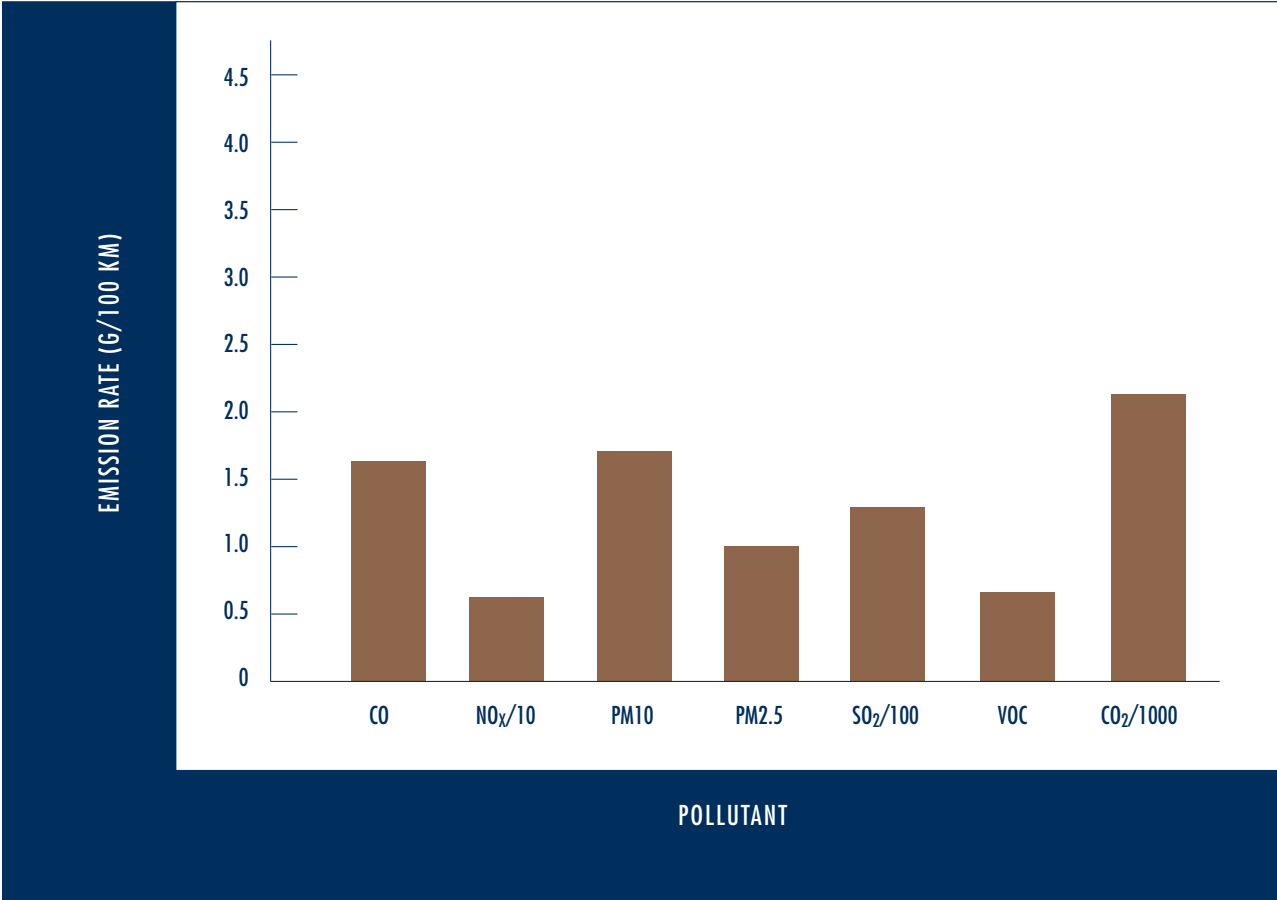


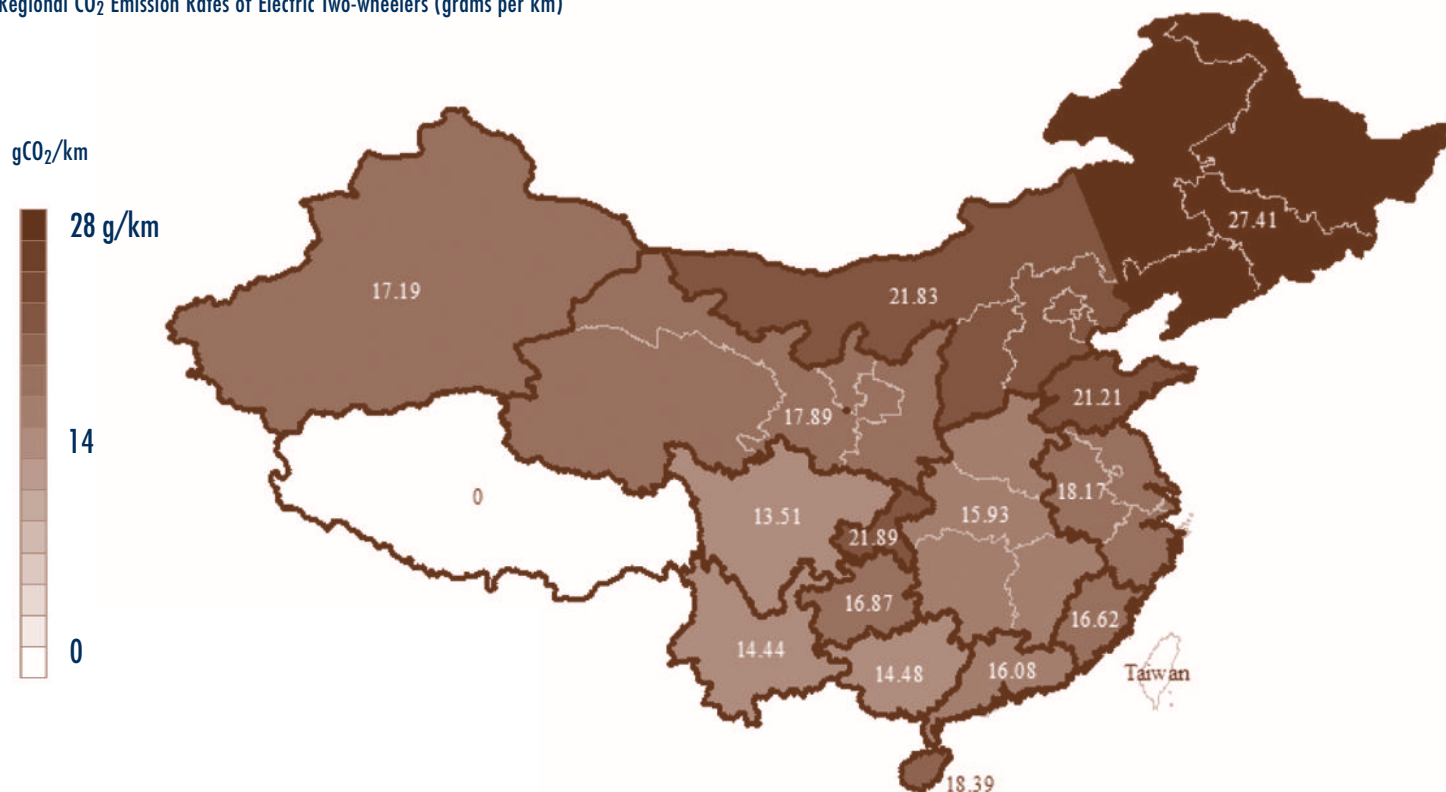


The low power required to operate electric two wheelers also makes them relatively clean. The primary factor determining the environmental impact of electric two wheelers is the method used to generate the electricity that powers them. Over 80 percent of China’s electricity generation relies on fossil fuels, mostly coal. However, different regions rely on fossil fuels to different degrees, so the location of a two-wheeler can significantly influence its environmental impact. Figure 2 shows average emission rates (weighted by total electricity generated in the region) of several pollutants from electric two-wheelers. In general, the provinces with the fewest emissions are in the southwest, which has cleaner hydropower sources of electricity, while the provinces with the highest emissions are in the northeast, where virtually all electricity is generated with coal (Figure 3).

Two-wheelers’ low emissions, however, are partly countered by their growing use of lead batteries. Over 90 percent of electric bikes in China use a lead battery, and each battery typically contains 10 to 20 kg of lead. Some of the largest electric scooters use even heavier batteries. Mining, producing and even recycling lead batteries can generate substantial pollution. While it is true that almost all motorized vehicles use lead acid batteries, none use them at the rate electric bikes do. Each electric bike requires a replacement battery every twelve to eighteen months, resulting in a tremendous amount of lead released to the environment. Moreover, battery recycling in China is >

**FIGURE 2**  
Electric Two-Wheeler Emission Rates



**FIGURE 3**Regional CO<sub>2</sub> Emission Rates of Electric Two-wheelers (grams per km)

poorly regulated, and generally only captures 70 to 80 percent of the used lead. This low recapture rate is largely due to a burgeoning industry of small, informal recyclers and manufacturers, whose existence is fueled by the popularity of two-wheelers. The high rates of lead emissions not only undermine the environmental advantages of two-wheelers, but also pose health threats to people who live near lead production and recycling facilities. In the past year, a number of high-profile lead poisoning cases have been reported around lead and battery manufacturing facilities throughout China.

Nevertheless, electric two-wheelers have some clear environmental advantages when compared to competing motorized modes. Table 1 shows the average emission rates, including vehicle and fuel production emissions, of several vehicles that electric two-wheelers compete with for mode-share. Even compared to a loaded bus (the vehicle most two-wheeler operators would otherwise be using), electric two-wheelers emit less carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), and nitrogen oxides (NO<sub>x</sub>). However, they emit *more* particulate matter (PM), sulfur dioxide (SO<sub>2</sub>) and hydrocarbons (HC) than buses, because they draw power from China's coal-based power grid. (And again, because different regions depend more or less heavily on coal, these comparisons can vary by region).

Compared to cars or motorcycles, electric two-wheeler emissions are significantly lower on almost all metrics. The big exception is lead (Pb). Because of their batteries, electric bikes emit far more lead than other modes, often by one or two orders of magnitude. Compared to motorcycles, electric two-wheelers perform very well on all metrics, with the

exception of lead and SO<sub>2</sub>, and cars have higher emissions than two-wheelers in every category except lead. Indeed, for most pollutants the emission rates of cars are one or two orders of magnitude higher than electric two-wheeler emissions.

For example, a new car in Beijing that meets emission standards for particulate matter will emit 0.005 grams per kilogram of particulate, and it will expose nearby residents to 73 parts per million (ppm) of exhaust emissions. For each million grams of particulate matter emitted, in other words, only 73 grams are inhaled. By contrast, an electric two-wheeler in Beijing, with an emission rate of 0.008 g/km (1.6 times *higher* than the emission rate of gasoline car), will expose the population to only 6 ppm of the total PM<sub>2.5</sub> emissions, a mere eight percent of a gasoline car's exposure rate. This implies that the public health impacts of electric two-wheeler emissions could be much lower than the public health impacts of automobiles, although the electric two-wheeler's emission rate is higher. The public health impact of electric two-wheelers is even more advantageous when they are compared to diesel cars and buses, which have higher tailpipe emissions *and* exposure rates.

Local emissions, however, don't tell the whole story. Electric two-wheelers are charged from the grid, so they contribute to pollution from power plants. Most pollutants from tailpipes are emitted in urban areas, and generally inhaled by the urban population. But power plants are frequently in rural areas, and their pollutants might be inhaled primarily by rural residents who live nearby, and who are not responsible for the bulk of the emissions. Thus while electric vehicle emissions and exposure could be lower overall, a large shift to electric vehicles could also shift urban transportation pollution onto rural populations.

**LOOKING BEYOND CHINA: A GLOBAL FUTURE FOR ELECTRIC TWO-WHEELERS?**

Electric two-wheelers are not nearly as popular outside China, probably because in other countries traditional motorcycles are not as severely restricted. In other Asian countries, electric two-wheelers compete directly with gasoline scooters. Electric two-wheelers in China, however, compete mostly against buses or bicycles. Moreover, because electric two-wheelers in China are slower and lighter than gasoline >



	CAR (1.5 pax)	BUS (50 pax)	MOTORCYCLE (1 pax)	ELECTRIC TWO-WHEELER (1 pax)
CO <sub>2</sub> (g/pax-km)	204	48.4	128	40.5
SO <sub>2</sub> (g/pax-km)	0.46	0.02	0.08	0.17
PM (g/pax-km)	0.19	0.07	0.4	0.19
CO (g/pax-km)	6.7	0.16	12.5	0.017
HC (g/pax-km)	1.1	0.015	2.25	0.064
NO <sub>x</sub> (g/pax-km)	0.88	0.27	0.15	0.027
Pb (mg/pax-km)	35	2	32	420

**TABLE 1**  
Emission Rates of Electric Two-Wheelers Compared to Alternatives Modes (Production and Use Emissions)





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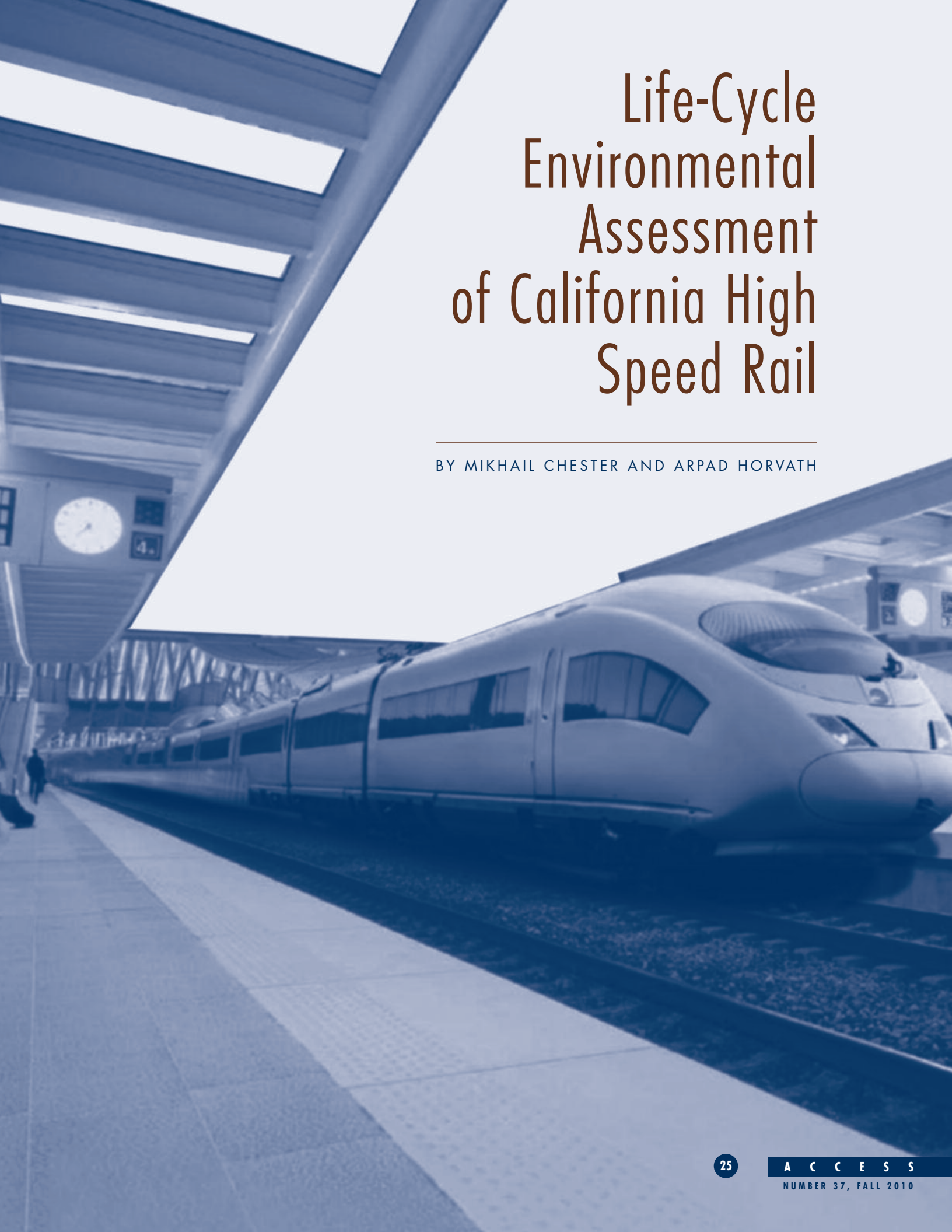
motorcycles (a result of the government regulations mentioned above), they are not a very viable export product. Electric two-wheelers that China exports to Asian countries like India and Vietnam have difficulty competing with faster gasoline two-wheelers; the combined Indian and Vietnamese market for electric two-wheelers is only one-tenth the size of China's. In response, some electric two-wheeler companies have begun marketing vehicles that can compete with gasoline vehicles on price and performance, but some of the initial models were low-quality, and consumers remain wary. However, if fuel prices rise in Asia and electric vehicle technologies mature, electric two-wheelers could become more popular, particularly if governments give them favorable treatment through reduced licensing requirements or sales tax incentives.

Absent such interventions, however, it is unclear how popular electric two-wheelers will be outside the unique circumstances of congestion and regulation that characterize Chinese cities. Some electric two-wheelers—primarily electric-assist bicycles with advanced battery technology and performance—are becoming popular in some European and North American cities. These vehicles are designed to travel longer distances and at higher speeds. As a result, they tend to be larger than traditional bicycles, which raises significant questions about their role and place in the transportation system. Nevertheless, electric two-wheelers in Western countries could help overcome many of the challenges associated with traditional bicycles by increasing their range, making difficult terrain more manageable, and reducing rider fatigue. But Western nations, like China, will need to devise and enforce rules defining how two-wheelers can safely travel.

## CONCLUSION

The Chinese electric two-wheeler market has exploded in the last decade. Streets in Chinese cities teem with electric two-wheelers vying for valuable space. The two-wheelers provide a tremendous amount of low-cost mobility, no tailpipe emissions, some of the lowest overall emissions of any motorized mode, and almost no noise. It is tempting to see China's experience as a prologue for the mass-adoption of electric two-wheelers in other parts of the world, and two-wheelers could well fill a niche in the West.

Yet China's experience also shows us the complications that can arise when another set of users is mixed into an already-crowded road system. In response to concerns about safety, the Chinese government has had to reinforce its distinctions between bikes, electric bikes and scooters, and Western countries will also require unique policies to classify electric two-wheelers and integrate them into the existing transportation system. Whether electric two-wheelers will be able to compete in the open market against gasoline two-wheelers also remains uncertain. ♦



# Life-Cycle Environmental Assessment of California High Speed Rail

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BY MIKHAIL CHESTER AND ARPAD HORVATH



CALIFORNIA IS PLANNING TO SPEND \$40 billion to build a high-speed rail system from San Diego to Sacramento. Advocates argue that high-speed rail will save money and improve the environment, while critics claim it will waste money and harm the environment. What accounts for these diametrically opposed views about a technology that has been operating in other countries for decades? And what can transportation analysts offer to inform the debate?

Disagreements about the cost and environmental impacts of high-speed rail can arise when analysts examine only the most direct effects of the rail system, and compare those to only the direct effects of road and air travel—the two transportation modes from which high-speed rail will likely draw passengers. But transportation energy use and emissions result not only from the direct effects of operating the vehicles but also from indirect effects, such as building the infrastructure, producing the fuels, manufacturing the vehicles, maintaining the system, and disposing of materials at the end of their lives. The full range of emissions from automobile travel, for example, includes not only tailpipe emissions but also the emissions created by building roads and parking garages, manufacturing cars, extracting and refining petroleum, and, finally, wrecking yards and tire dumps. One approach to environmental and cost-benefit analysis that takes both these direct and indirect effects into account is *life-cycle assessment*. In this article we use life-cycle assessment to compare the energy use and pollution emissions of high speed rail and its competing modes.

#### LIFE-CYCLE VERSUS NARROWER ACCOUNTING APPROACHES

When analyzing the environmental effects of planes, trains or automobiles, the normal approach is to measure tailpipe emissions. Researchers can estimate these emissions with a variety of methods, and then combine the emissions data with information about typical vehicle occupancy. Together, these data can be used to calculate the *emissions per passenger-kilometer of travel* for each mode.

The problems with this approach are twofold. First, it often ignores the large differences *within* modes. The environmental costs of cars, for example, will vary with drive cycles, technology, age, and the composition of the fleet. So while it may be tempting to say that one mode is simply better than another, environmental policy should recognize that no mode is universally good or bad, and that environmental impacts will depend heavily on context. Second, the conventional approach to evaluating modes depends heavily on estimates of ridership or occupancy. But calculating ridership is always hard, and for an entirely new system, such as California's high-speed rail, the task is particularly challenging. Because the system doesn't exist yet, ridership estimates are less certain, forecasted from surveys and travel demand models rather than extrapolated from existing data. But even small adjustments to ridership estimates (or, for cars, occupancy estimates) can substantially change an environmental impact analysis. For example, how should we evaluate a new rail track that will last for decades? The track will likely facilitate many vehicle-kilometers of travel, but the emissions per *passenger-kilometer* will depend crucially on how many people will ride the trains. But even our best ridership estimates are uncertain, so picking a number and settling on it creates a false sense of precision. It is both more useful and more honest to evaluate different modes based on a *range* of possible ridership estimates.

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**THE LIFE-CYCLE LENS**

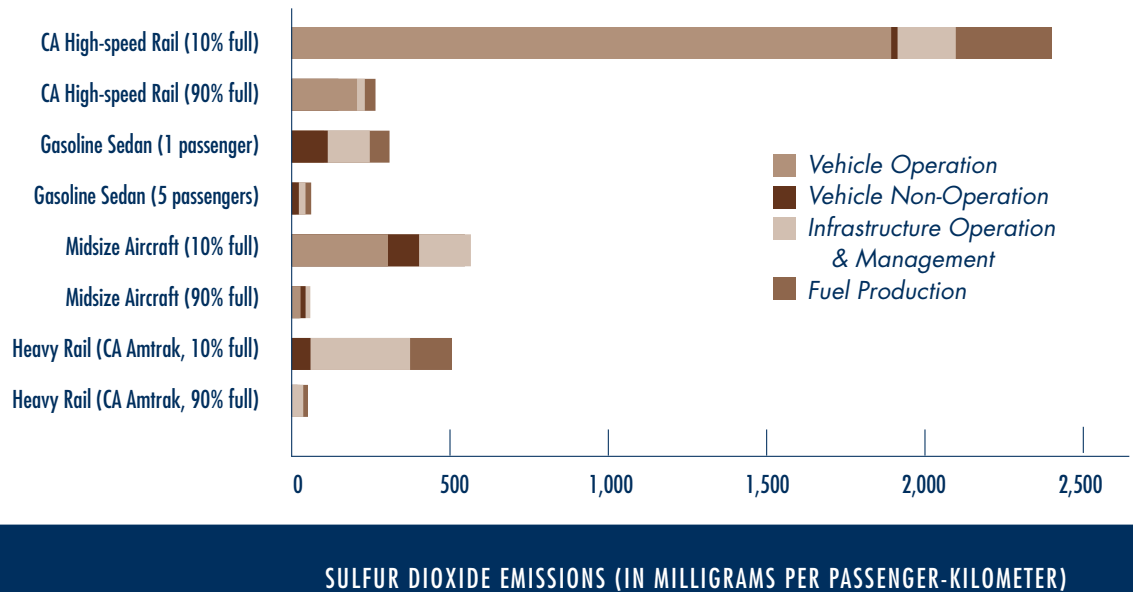
Taking life-cycle and ridership uncertainty into account can yield drastically different estimates about the energy efficiency of different transportation modes. To illustrate this point, we assembled comprehensive data on energy use for 30 different on-road, rail, and air transportation modes, ranging from small automobiles to large aircraft. For each mode, we have information for 79 unique life-cycle components, including not just operating the vehicles, but also manufacturing the vehicles, constructing the infrastructure, performing maintenance, and producing fuel. For each mode at each life-cycle stage, we have quantified the energy inputs and emissions of greenhouse gases, sulfur dioxide, carbon monoxide, nitrogen oxides, volatile organic compounds, and particulate matter. Some of our results are shown in Figure 1, and they demonstrate the importance of considering both indirect impacts and ridership estimates.

For example, light rail with 90 percent occupancy would compare favorably with just about any other mode if we consider only the energy expended and emissions created in *operating* the system. But building the infrastructure and producing the fuel essentially *doubles* the energy intensity of light rail. And if we change our assumptions further >

**FIGURE 1**

Life-cycle Energy Consumption for On-road, Rail, and Air Modes





**FIGURE 2**

Life-cycle Sulfur Dioxide Emissions for California Corridor Modes

and assume that the light rail system will be only 10 percent full, as opposed to 90 percent, then light rail starts to look much worse, and is less environmentally beneficial than a gasoline sedan with a solo driver.

The reasons for the large non-operating impacts vary. Regulations have greatly reduced sulfur levels in fuels, so the majority of sulfur dioxide emissions now come from burning fossil fuels to generate the electricity needed to manufacture vehicles, build and operate infrastructure, process materials, and produce fuel (see Figure 2). In fact, the majority of sulfur dioxide, carbon monoxide, volatile organic compounds, and particulate matter emissions now come not from vehicle operation but from other life-cycle components. For bus, rail, and air modes, producing and transporting cement (for roads and runways) can produce more carbon monoxide than operating the vehicles. And airport equipment, such as baggage tractors, can generate three to nine times more carbon monoxide emissions than actually flying the aircraft.

A life-cycle analysis also allows us to see the environmental impacts of a given transportation mode far beyond where the travel occurs. For example, manufacturing a car or propelling a train requires electricity, and the fossil fuels burned to generate that electricity produce sulfur dioxide emissions that can harm human health outside the regions where people drive the cars or ride the trains. Similarly, particulate matter emitted from a hot-mix asphalt plant harms people near the plant, rather than where travel occurs. When we evaluated the life-cycle externalities associated with the healthcare costs of treating exposure to emissions from urban travel, we found that the external costs of travel were as high as 11¢ per passenger-mile for automobile trips and 19¢ per passenger-mile for public transit trips. While these worst-case costs occur only when the highest environmental impact and lowest ridership are assumed, the assessment suggests the importance of encouraging passengers to shift to cleaner and higher-ridership modes.

## LIFE-CYCLE ANALYSIS OF CALIFORNIA HIGH-SPEED RAIL

The proposed California high-speed rail system offers an opportunity to compare new rail transportation infrastructure against continued growth in auto and air travel. Most of the high-speed rail debate centers on the cost of building the system, with little attention paid to the cost of some alternatives, such as expanding the road and air infrastructure in the corridor or using congestion pricing on roadways and peak landing fees at airports. California's population is expected to increase significantly in the next half century, and the demand for travel will likely rise as well. High-speed rail will divert some of this additional travel demand from auto and air modes, but will doing so benefit the environment? Life-cycle analysis can provide the broader understanding needed to answer this question by considering more than only vehicles and fuels.

We have developed a life-cycle inventory of high-speed rail, automobiles, heavy-rail (Amtrak), and aircraft in the California high-speed rail corridor from San Diego to Sacramento. Currently, autos account for 75 percent of corridor's total passenger travel, air 24 percent, and heavy rail only 1 percent. Our life-cycle inventory evaluates the vehicle, infrastructure, and fuel components of all these modes, and takes into account conditions that are specific to California: how the vehicles used here are made; the source of electricity behind the various modes; and typical ridership levels for in-state long-distance trips. A key factor is the cleanliness of the electricity used by each mode. High-speed rail proponents have recently acknowledged the need to augment any new train infrastructure with investments in wind and solar electricity generation in order to reduce emissions. But the high speed rail authority has no clear directive to use renewable electricity, so we assumed that high-speed rail will use the current regional electricity mix. We also assumed the rail line will operate 1,200-seat trains as indicated in the California High-Speed Rail Authority's environmental impact statements. These are big trains: European and Japanese high-speed trains often seat 600 or fewer passengers.

The life-cycle inventory for high-speed rail shows that accounting for infrastructure construction and electricity production adds 40 percent to the energy consumed by the trains' operations alone (see Figure 1). Greenhouse gas emissions increase by about 15 percent, primarily because of the concrete used in construction—half a kilogram of CO<sub>2</sub> is emitted for every kilogram of cement produced. Infrastructure construction will emit roughly 490 million metric tons of greenhouse gases, which are approximately 2 percent of California's current annual emissions. As was the case with the life-cycle inventory of conventional modes, the majority of emissions are released not from the electricity needed to propel the high-speed trains, but from the indirect and supply-chain components.

We can estimate the energy payback period for high-speed rail by comparing the energy used in its construction with the resulting energy savings in its operation, but only by making assumptions about ridership. The payback period evaluates the upfront energy or emission investment in deploying high-speed rail infrastructure against the potential reductions over time. The California High-Speed Rail Authority provides a ridership estimate, but as we noted above, ridership is uncertain, and for an entirely new mode it is very uncertain. Thus California high-speed rail warrants ridership evaluation for both high- and low-ridership scenarios. We consider high ridership as strong adoption of high-speed rail at the expense of auto and air travel, mid-level ridership as moderate adoption of high-speed rail, and low ridership as poor adoption of high-speed rail where travelers favor auto and air. For high ridership scenarios, the energy payback period >





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on the initial investment is eight years, for mid-level ridership 30 years, and never for low ridership (when under-used high-speed rail is coupled with increased utilization of auto and air travel). For greenhouse gas emissions the payback period for rail is six years for high ridership, 70 years for mid-level ridership, and never for low ridership. Sulfur dioxide emissions, primarily from electricity production throughout the life-cycle, show a surprising payback result; there is no reduction in sulfur dioxide emissions for any rail ridership scenario if electricity continues to be generated and supplied as it is currently.

Thus the California high-speed rail system can reduce greenhouse gas emissions, but may do so only over a very long period, and will do so in exchange for other air emissions. This dilemma illustrates the potential pitfall of tackling reductions of one pollutant, like carbon emissions, without considering other emissions. Building high-speed rail to reduce carbon emissions should also include co-investment in clean electricity to avoid unintended consequences like increases in sulfur dioxide. The life-cycle assessment framework highlights the pitfalls of shifting emissions from the tailpipe to other processes, and evaluating the new rail system prior to design offers direction for minimizing effects in the larger transport system.

## SYSTEMS-ORIENTED POLICY ANALYSIS

Energy and emissions policies have often been adopted with little recognition that one negative environmental impact is often being traded for another. The addition of MTBE as a fuel oxygenate in the 1990s and the more recent use of corn-ethanol are two prime examples. Rigorous life-cycle assessment of either fuel additive would have revealed tradeoffs, which for both were realized only after widespread use. The decision to use MTBE to improve air quality failed to consider the fuel additive's release into groundwater supplies when stored in leaky underground tanks. And the broad agricultural, economic, and environmental food-versus-fuel tradeoffs of corn ethanol are only now beginning to be understood.

For California high-speed rail, life-cycle analysis offers a way to identify tradeoffs early in the policy development and planning phases. Our life-cycle analysis of California high-speed rail shows that its total energy use and greenhouse gas emissions per passenger-kilometer will be significantly underestimated if analysts consider only operating the trains, and if they over-estimate the ridership. Extensive use of concrete and other materials, transportation of parts and materials in the supply chain, and electricity generation for many interrelated processes will consume much energy and produce much pollution before the trains begin transporting passengers. Accounting for these life-cycle effects and for the large range of potential ridership shows that California high-speed rail can be either better or worse for the environment than air or car travel. It is critical that before deploying high-speed rail, several key factors are comprehensively examined to ensure the system environmentally outperforms existing modes. These factors include the use of more frequent, smaller trains coupled with station placement that incorporates long-term regional planning and existing transit integration to promote high ridership. Electricity for trains and infrastructure should be generated from clean sources. And for infrastructure construction, the environmental impacts of certain materials, like concrete, should be minimized. Furthermore, mode shifting behavior and indirect effects including reduced congestion should be considered. Life-cycle assessment shows that high ridership coupled with planning for system-wide energy and emission reductions are necessary for a high-speed rail network to improve the environment and human health. ♦



# MEGACITIES AND MEGATRAFFIC

BY MARK KUTZBACH

**S**CAN THE NEWSPAPER IN ANY BIG CITY of a rapidly developing country and you will probably see complaints about traffic congestion. Traffic congestion in developing megacities not only aggravates commuters but also isolates them with time-consuming, unreliable, and expensive commutes. In Mumbai, India, for example, *The Mumbai Mirror* reported in early 2010 that India's champion athletes missed the closing ceremony of the South Asian Games due to the city's "never-ending traffic jam."

The increasing motorization of developing countries is a testament to their economic growth, and to their citizens' aspirations to faster and more comfortable travel. However, the commensurate increase in congestion on already crowded streets is threatening to isolate workers from employers, and to incapacitate the bus systems that many middle- to low-income commuters still rely on. Motorization can also be difficult for policymakers to respond to, because it often happens with startling speed. Why some countries adopt cars so much more rapidly than others is the puzzle I address in this article. ➤

## RIISING INCOMES AND MOTORIZATION

As a general rule, rising incomes lead to increased car use and worse traffic congestion. The streets of cities in developing countries serve multiple travel modes, reflecting the wide range of incomes among commuters and the variety of trip lengths and purposes. Compared to developed countries, many developing countries have large fleets of common-use vehicles, including public buses, private and often informally operated minibuses, and shared taxis (including motorcycle taxis). As incomes rise and cities grow, commuters switch from walking or bicycling to public transportation, usually buses, in an attempt to save their increasingly valuable time.

Buses are efficient, but cars are faster and more comfortable. For example, the average bus in Sao Paulo, Brazil, travels 15 km per hour, while the average car travels 25 km per hour. This faster travel speed, along with the ability to change routes and the benefit of door-to-door service, is more attractive to higher-income commuters who place a higher value on their time and can spend more money on commuting. Surveys routinely find higher rates of car ownership and usage among higher income households.

But income alone cannot explain motorization because countries with similar income levels often have widely varying levels of car use. Ascertaining why this is the case is difficult, not least because there is little reliable data on vehicle use that is comparable both across time and across countries. The best available data come from the International Road Federation's (IRF) World Road Statistics. Comparing the IRF's data on passenger cars per 1,000 people with the World Bank's data on per-capita income shows that rising incomes are, unsurprisingly, associated with increasing car ownership. The arrows in Figure 1 track the change in income and car ownership for a selection of countries from 2002 to 2007 (with both axes on a logarithmic scale). Note the astounding growth of China, where per-capita incomes almost doubled and car use almost tripled. Car ownership rises with per capita income within each country, but large, unexplained differences between countries remain.

For example, consider the middle-income countries of Botswana, Chile, and Malaysia. All three countries have similar per-capita incomes, around \$10,000 a year, but Botswana has only 55 cars per 1,000 people, while Chile has about 100 and Malaysia has over 200 cars per 1,000 people. Similarly, Pakistan and Nicaragua are both lower-income countries, with incomes around \$2,000 a year. Nevertheless, Pakistan has only 8 cars per 1,000 people while Nicaragua has 18, over twice as many. What accounts for these differences?

## THE ROLE OF INCOME INEQUALITY

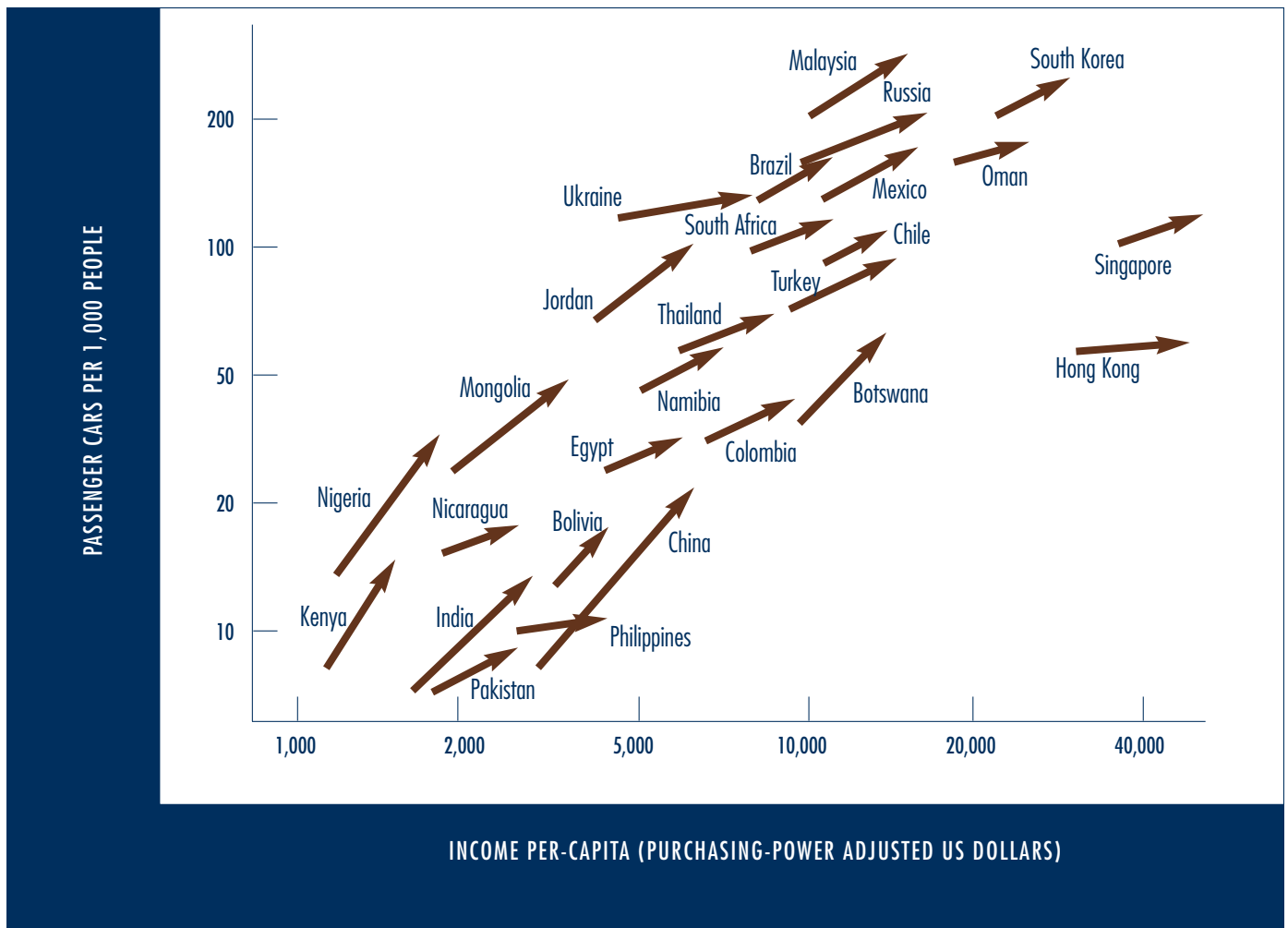
Consider two low income countries, one of which has high inequality and the other a more equal distribution of income. Because a certain minimum level of income is necessary to buy and maintain a car, the unequal society, which has a larger share at the upper end of its income distribution, may initially have a larger share of car owners than the more equal society. The equal society may have some high-income car users, but the bulk of its population is concentrated in a bus-using middle class.

*Income alone cannot explain motorization because countries with similar income levels often have widely varying levels of car use.*

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**FIGURE 1**

Motorization and economic growth in developing countries: 2002–2007.

Scale is logarithmic

The positive relationship between inequality and car ownership can reverse, however, as countries develop and overall incomes rise. When per-capita income rises in the unequal society, the rich, who already own cars, continue to get richer, but the poor, who did not have cars, may still be too poor to afford them. In contrast, rises in per-capita income in the equal society accrue broadly across the population of commuters, pushing the bulk of the middle class into cars. Because a country with more equal income distribution has a larger middle class, car purchases may occur quickly across a large share of the population, resulting in a rapid increase in car use.

To illustrate the relationships among income inequality, economic growth, and car ownership, consider some of the countries mapped in Figure 1. Among low-income countries, with per-capita incomes around \$2,000 a year, high inequality countries in Latin America, such as Nicaragua and Bolivia, tend to have higher car ownership than the more equal societies of South and East Asia, such as India and the Philippines. This order tends to be reversed for middle income countries, with incomes around \$10,000 a year, where more equal Asian and former socialist countries, such as Malaysia, Russia, and South Korea, have higher car ownership than less equal African and Latin American countries, such as Botswana and Colombia. ➤



#### THE ROLE OF TRAFFIC CONGESTION

Inequality can influence car use at a national level; once people begin adopting cars, however, the changing composition of the vehicle fleet can trigger further changes within cities. In particular, commuters who switch to cars reduce the efficiency of buses and increase traffic congestion, which induces even more bus commuters to switch to cars. As transportation economist Herbert Mohring explained, the more people who use a bus system, the more time- and cost-efficient it becomes. The increasing ridership justifies increasing the frequency of service, with more routes improving accessibility and higher occupancy reducing the cost per user. These changes encourage further ridership, creating a positive feedback effect—a “virtuous circle.” But the reverse happens when bus use declines and service degrades—a “vicious circle.”

In developing countries, rising traffic congestion, fuelled by rapid motorization, can tip the balance toward a vicious circle by increasing bus travel time relative to car travel time. A reasonably full bus uses road space more efficiently than cars do, so each car driver contributes more to congestion than each bus rider. But even in cities where the vast majority of commuters travel by bus—such as Lima, Peru and Nairobi, Kenya—the majority of vehicles on the road are cars. And while buses contribute less to congestion than cars, they also *adapt* to congestion more poorly. Buses have more difficulty maneuvering on congested streets than do cars, and in particular they have more difficulty getting to the curb to make their frequent stops. Thus while buses account for little of the causes of congestion, they absorb a disproportionate share of the costs. The highest income bus riders are nearly indifferent between slower, cheaper bus travel and faster but more expensive cars. When bus travel time increases, therefore, these riders soon switch to cars. As incomes rise, congestion worsens, bus travel slows, and more commuters buy a car. Because of the increase in traffic congestion, even lower wage commuters who have a lower value of time will come to prefer car travel. And as these commuters switch to cars,

more traffic congestion induces even more switching between modes. Eventually, when income changes abate, bus use stabilizes at a lower, equilibrium level.

This transition has the potential to be very rapid, and would most likely occur when middle class workers begin to switch to cars. Eventually, with degraded service and longer wait times, even many of the poor may stop riding the bus.

### THE ROLE OF TRANSPORTATION POLICY

Rising incomes are not always associated with rapid increases in motorization. Singapore and Hong Kong are economic success stories, but maintain rates of 112 and 54 cars per 1,000 people respectively. Singapore maintained stable car ownership by imposing high taxes on vehicle licenses, supporting public transport, and introducing a cordon toll on car travel into the center of the island. Hong Kong established an extensive system of rail, tramways, buses, ferries, and even outdoor moving sidewalks. Today it has one of the highest rates of public transport use in the world. Nevertheless, Singapore and Hong Kong are unique because they are island city-states where natural and political barriers prevent sprawl and require them to grow ever denser. Furthermore, their institutional structures have enabled them to implement bold programs that would likely be politically infeasible in more democratic countries.

In contrast, many megacities in developing countries seem almost unbounded spatially, and many policy interventions have failed. Schemes such as Mexico City's even-odd driving days (where vehicles with license plates ending in odd numbers cannot be operated on certain days, and vehicles with even numbers cannot operate on other days) have not reduced the relative benefits of traveling by car. Ironically, these policies have spurred travelers to purchase second, alternate-day cars. One intervention that has spread rapidly in the last decade is Bus Rapid Transit (BRT). In the 1970s, Curitiba, Brazil pioneered this approach by restricting some lanes to bus travel and investing heavily in supportive bus infrastructure. Moreover, Curitiba has pioneered complementary land use planning. As a result, even as incomes and values of time have risen, a large share of the middle class continues to ride the bus. Cities across Latin America, and now in Asia and Africa, are investing in BRT systems with the help of funding and technical assistance from international lenders.

Once people buy cars, they probably will not return to public transportation. Thus one key to Curitiba's success was investing heavily in the bus system and supportive land use planning just before the explosion of middle class motorization would have begun.

### THE CONGESTED ROAD AHEAD

Even in Curitiba, car use has risen substantially due to steady economic growth. With the roll-out of multi-national Tata's very affordable Nano to the Indian car market in 2009, the income threshold necessary for car ownership is likely to fall. Even in the recent recession, Tata has been swamped with orders for the Nano, and annual car sales in India have continued to rise. Beyond changes in travel costs and the value of time, preferences for the status and independence of private transportation also fuel modal shifts. While rising incomes may induce more people to buy cars, driving them will not be peaceful or efficient. Early interventions, like reserved bus lanes, can benefit everyone by providing a low cost yet comparably efficient alternative to car travel and by maintaining connectivity in ever growing megacities. ♦

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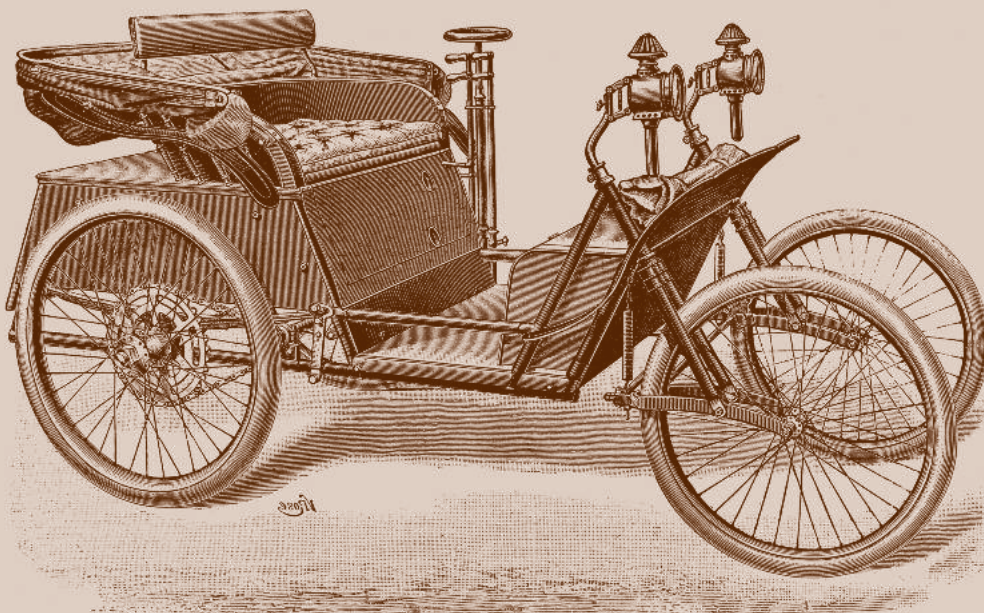
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# Graduated Parking Fines

BY DONALD SHOUP

CITIES OFTEN INCREASE THEIR PARKING FINES WHEN they need more money. Los Angeles, for example, is facing a major budget crisis and increased its fines for all parking tickets by \$5, regardless of the violation. This across-the-board hike suggests that the higher fines are more about raising money than about enforcing the law. But a few cities have discovered how to enforce the law and raise money without costing most drivers anything. Cities can achieve these three goals by using graduated parking fines.

Fines are necessary to enforce parking regulations, and enforcement is important because violations have victims. If a driver stays over the time limit, others have a harder time finding a space and businesses can suffer from low turnover. Double parking can block a whole lane of traffic. Illegal parking in a disabled space makes life even more difficult for people with disabilities.

Setting the right fine for each parking violation is complicated because a few repeat violators often account for a large share of all violations. In Los Angeles, for example, 8% of all the license plates that received tickets in 2009 accounted for 29% of all the tickets in that year. In Beverly Hills, 5% of license plates accounted for 24% of all tickets. Californians are not the only serial offenders. In Manchester, NH, 5% of the plates accounted for 22% of all tickets and in Winnipeg, Canada, 14% of the plates accounted for 47% of all tickets.

Most drivers rarely or never receive a parking ticket, and for these drivers modest fines are a sufficient deterrent. But the many tickets for a few repeat offenders suggest that modest fines will not deter drivers who view parking violations as an acceptable gamble or just another cost of doing business. However, if cities raise parking fines high enough to deter the few chronic violators, they unfairly penalize many more drivers for occasional (and often inadvertent) violations.

Graduated parking fines are a way to deter chronic violators without unfairly punishing anyone else. Graduated fines are lenient for the many cars with only a few tickets but punitive for the few cars with many tickets. In Claremont, CA, for example, the first ticket for

overtime parking in a calendar year is \$35, the second \$70, and the third \$105. For illegally using a disabled parking space, the first ticket is \$325, the second \$650, and the third \$975.

For minor violations like overtime parking, some cities issue a warning for the first offense and graduated fines for subsequent offenses. The warnings show citizens that the city aims to encourage compliance rather than to raise revenue. Because parking tickets create hostility toward both the enforcement officers and City Hall, a warnings-first policy for minor offenses can reduce political opposition to enforcement. Repeat offenders will pay more but everyone else will pay less.

Until recently, graduated parking fines were impossible because enforcement officers had no way of knowing how many previous tickets a car had received. Now, however, officers carry handheld ticket-writing devices that wirelessly connect to the city's ticket database. These devices can automatically assign the proper fine for each violation according to the number of previous tickets for the license plate.

A driver who receives many tickets for the same offense is probably either careless, unlucky, or a scofflaw. Risking a ticket may thus be a rational choice. A study by the Boston Transportation Department, for example, found that the price of a ticket multiplied by the probability of citation for illegal curb parking was often less than the price of off-street parking for three or more hours, so the temptation to risk a ticket is strong. Scofflaws can do a simple cost-benefit calculation; they may get a ticket for one in 10 violations, but the conventional fines never increase. Higher fines for serial violators can reduce the total number of violations without harshly penalizing anyone else. Graduated fines are therefore fairer and more effective than flat-rate fines.

Most cities will no doubt continue to rely on parking fines to help balance the budget, but the next time they need more money from this source, cities should increase the fines for chronic offenders without unfairly penalizing everyone else.

This article was originally published in the *Los Angeles Times*.





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